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

Case study: HEFA pathway / palm oil

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Executive summary

- The case studies were developed with the aim of illustrating the use of the information available in the database to evaluate the potential of SAF 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 studies reported here address the production of SAF through the HEFA-SPK route, from palm oil. It was considered the production of palm oil at seven locations and the possible production of SAF at two oil refineries - REVAP, in the southeast, and RNEST, in the northeast of Brazil; however, there are some sites where the potential is limited. It was assumed that palm oil would valued according to market prices (2018 average prices were considered).
- The estimated minimum selling price (MSP) of SAF would vary from 19.7 to 28.5 €.GJ^{-1} (845-1,224 €.t^{-1}), mainly depending on where the production of palm oil takes place and on the industrial scale of industrial production. Strictly comparing estimated SAFs, there is a small advantage for the production at REVAP, but in all studied cases the transport of palm oil would have a significant impact.
- In practice, a constraint is that the best potential for palm production is in contentious regions from a socioeconomic and environmental points of view, and distant from where the industrial infrastructure is located. In addition, it seems a challenge to have SAF production recognized as sustainable, first because of the potentially low contribution to avoiding GHG emissions. Likewise, the investor should pay special attention to aspects associated with deforestation, actions that would guarantee the preservation of native vegetation to some extent, and the non-involvement with conflicts related to the violation of land and water use rights.

Summary

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

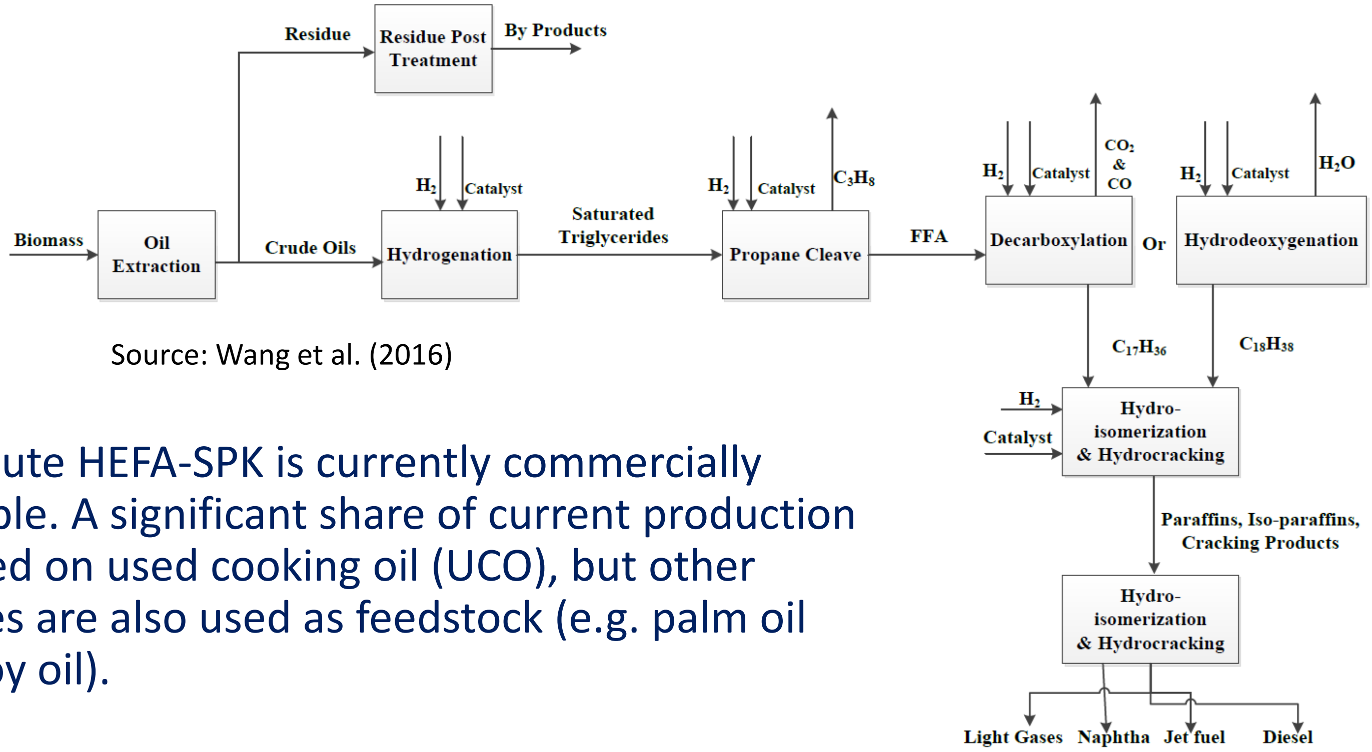
About the pathway (1)

- 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).
- For this route, feedstocks in the platform 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.
- Here, the reported case study is about the use of palm oil as feedstock.

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)

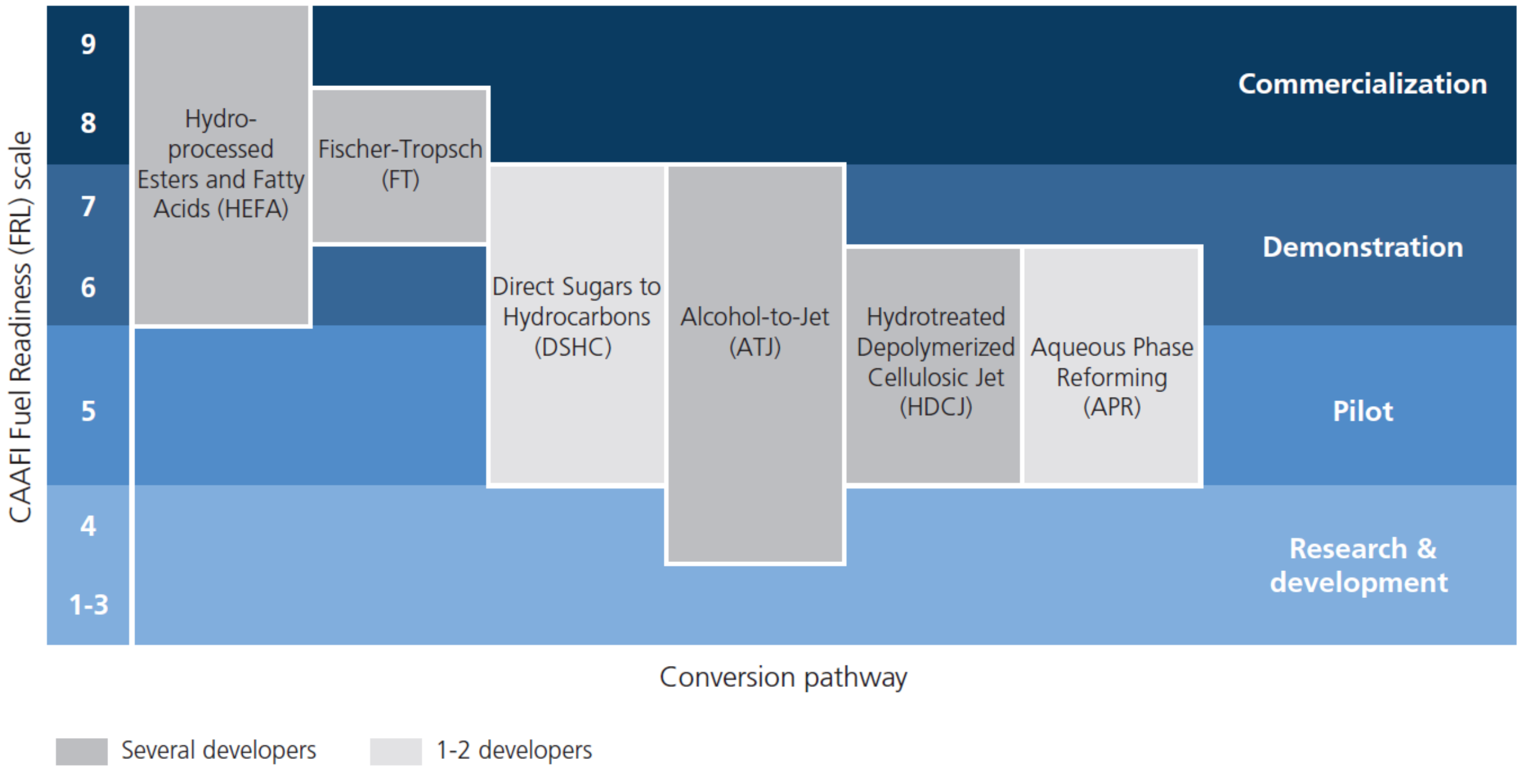


Source: Wang et al. (2016)

- 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 and 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 stages like 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 for HEFA-SPK.

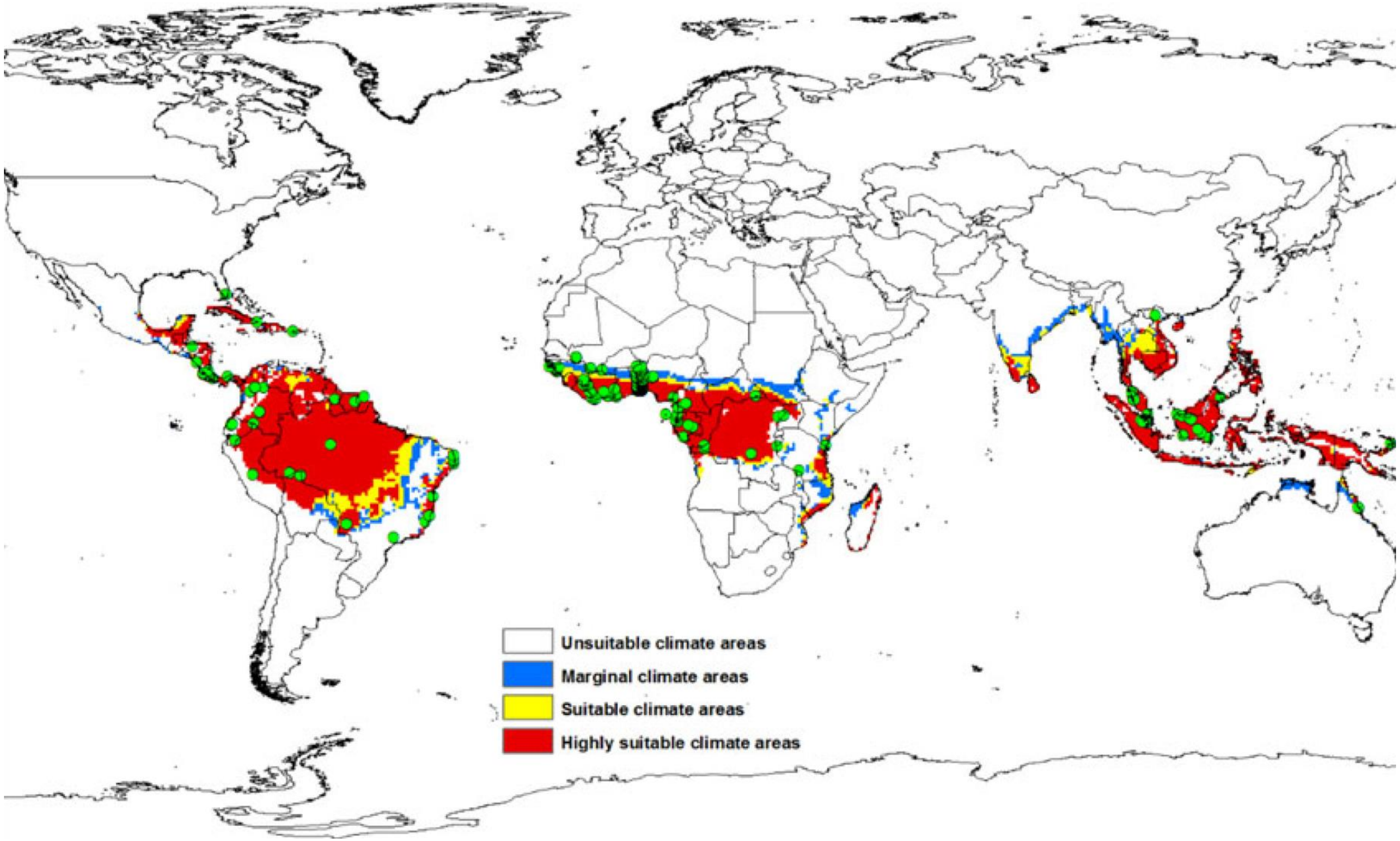
About palm oil (1)

- Palm (*Elaeis guineensis Jacq.*) is the source of most produced vegetable oil (according USDA (2020), about 36% of the total world production in 2019 (in mass basis). It is used in cooking, in the production of food, cosmetics, pharmaceutical products and also as a raw material in the production of biodiesel (Paterson et al., 2017).

About palm oil (2)

- It is often called African palm because of its origin. Palm was introduced in Southeast Asia in the 1960s and it is there that currently most of its oil production takes place: in Indonesia (about 55%) and in Malaysia (28%). Brazilian production in 2019 represented less than 1% of the world total (Agrianual, 2020).
- The palm oil itself (marketed as CPO - crude palm oil) comes from the pulp of the fruit (i.e. the mesocarp). Palm kernel oil (PKO) is also produced from the almonds, and it is more saturated than palm oil. The production of palm oil is about ten times larger than the production of PKO (EMBRAPA, 2004). Due to the rapid acidification of the fruits, there is a need to extract the oil no later than 24 hours after harvest.
- What is harvested is the bunch of fresh fruits (FF). The figures above show a bunch after harvest (right side) and several bunches after transport to the processing unit. On the previous slide, the photo on the left side shows manual harvesting.

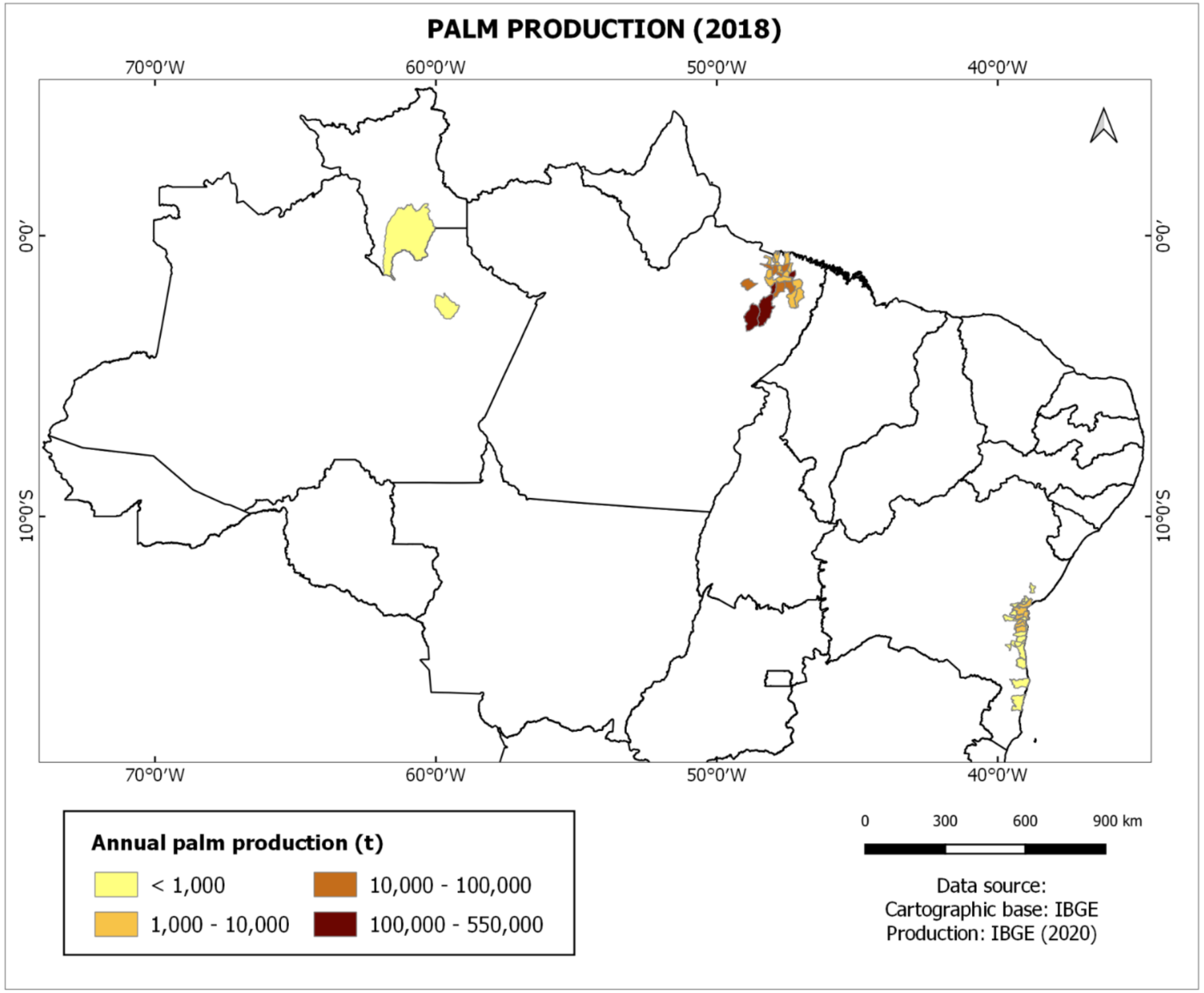
About palm oil (3)



- The humid tropical regions have the ideal climatic conditions for the crop. The figure (Paterson et al. 2017) shows the suitable areas around the globe. The dots represent existing oil palm occurrence.
- Suitability from a climatic point of view includes the following aspects (EMBRAPA, 2006; MAPA, 2018):

1. The annual rainfall above 2,000 mm, regularly distributed during the year, without water deficit;
2. More than 2,000 hours of sunshine and well distribution along the year;
3. Average air temperature between 24°C and 28°C, with an absolute monthly minimum of not less than 18°C;
4. The average monthly relative humidity should be between 75% to 90%.

Palm oil in Brazil (1)



- According to IBGE (2020), the production of palm oil in Brazil is concentrated in Para state (almost 98% of the total, in 2018), with a small production in Bahia (about 2%) and irrelevant registers (mass basis production) in Roraima and Amazonas.
- Also according to IBGE, almost 85% of the national production in 2018 was in only five municipalities in Para state: Tomé-Açú (30%), Tailândia (23%), Concórdia do Pará (13%), Acará (10%) and Moju (8%). The production is concentrated in Para northeast, as can be seen in the figure.
- Production started in Bahia, in the 1950s, and was introduced in Pará in the 1960s. In Bahia, palm oil is a central element in local cuisine, being used in the most traditional dishes (e.g. acarajé and vatapá).

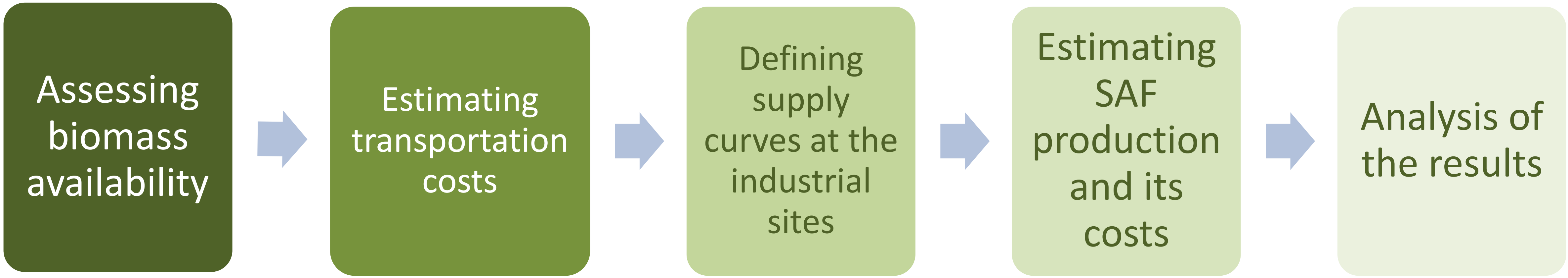
Palm oil in Brazil (2)

- In 2010, the Federal Government created a program with the objective of promoting sustainable palm production in Pará, and at that time developed a agro-ecological zoning. The Sustainable Palm Oil Production Program (SPOPP) aimed to support palm cultivation as a means for inclusive economic development and also to diversify raw materials for the production of biodiesel (Benami et al., 2018).
- The production in Pará is coordinated by the industry, while in Bahia it is extensive, with few technology applied. Moreover, the productivity registered in Bahia is low because the variety grown there (dura) is different from that used in Pará (tenera). Dura is more resistant to pests and diseases, coexists with weeds, and can produce for more than 40 years, but its yield is lower (Silva et al., 2016).
- ABRAPALMA (http://www.abrapalma.org/en/) - an association of palm oil producers - claims that current Brazilian production can only meet 60% of domestic demand. The association is very important in the state of Pará, and about 80% of the total cultivated area in Brazil belongs to the associated companies.
- Agropalma (https://www.agropalma.com.br/en) has all its production, including family farmers and integrated producers, certified by the RSPO - Roundtable on Sustainable Palm Oil. In 2014, its certified production area represented almost 60% of the total area harvested in Pará. The bulk of its production is in Tailândia.

Cases studied

- This case study corresponds to the production of SAF through the route HEFA-SPK, from 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).
- Palm production would be in there different states (Pará, Mato Grosso and Bahia), and oil extraction would occur in seven municipalities in these states (three sites in Pará, two in Mato Grosso and two in Bahia). Reasons for these assumptions are further presented.
- As long as the availability of palm oil is sufficient, five industrial capacities were considered in order to assess the feasibility. The feasibility is expressed by the minimum selling price of SAF. The temporal context is mid to long-term as it is considered that technology would be mature (n-th plant) and production at reasonable scales would possible.

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

- Palm suitability;
- Areas available and where production is desirable;
- Potential yields based on literature review;
- Estimated palm production costs;
- Transport of fresh fruits 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

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

→

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

Methodology … assessing costs and analysis of the results

SAFmaps

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)

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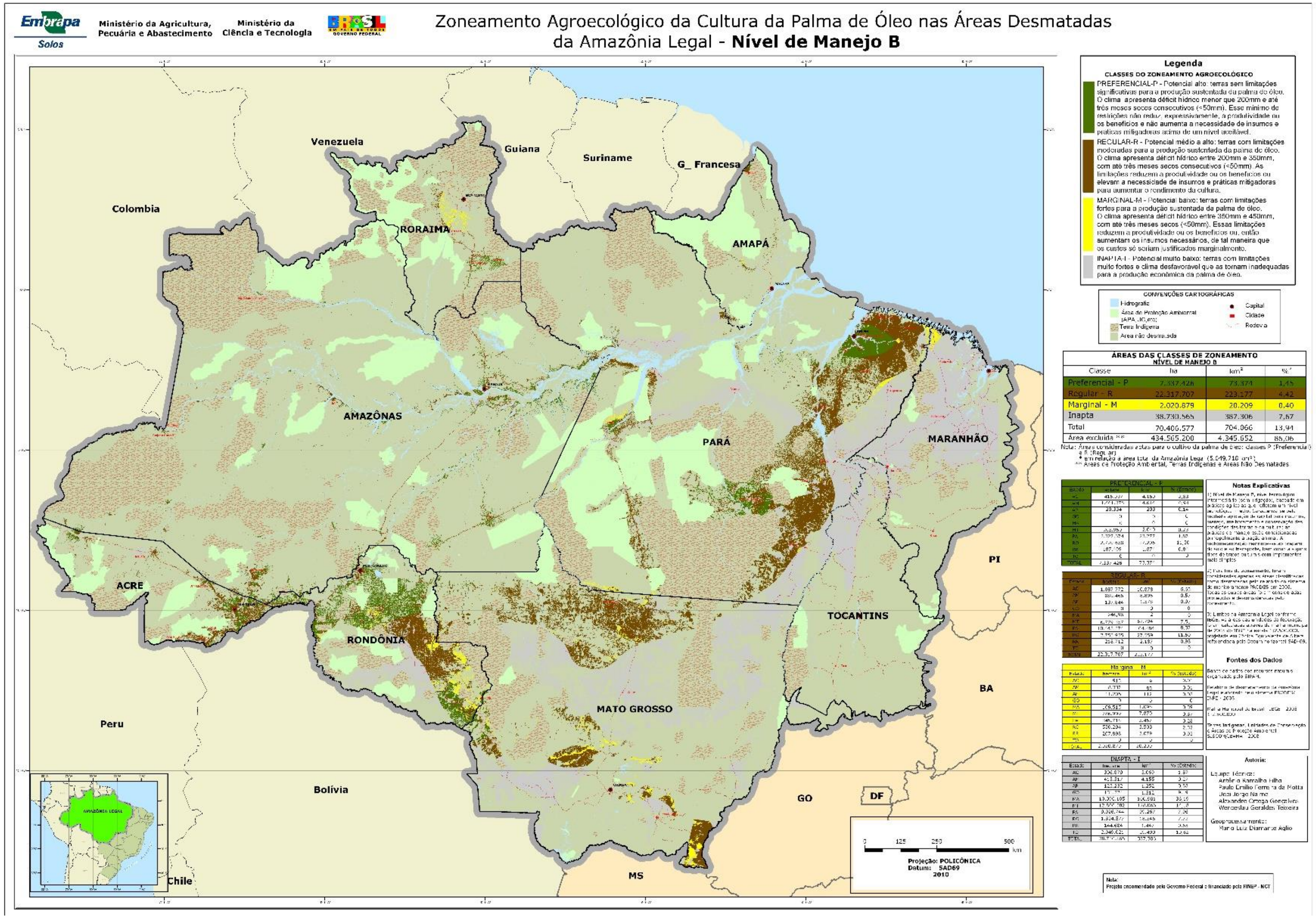
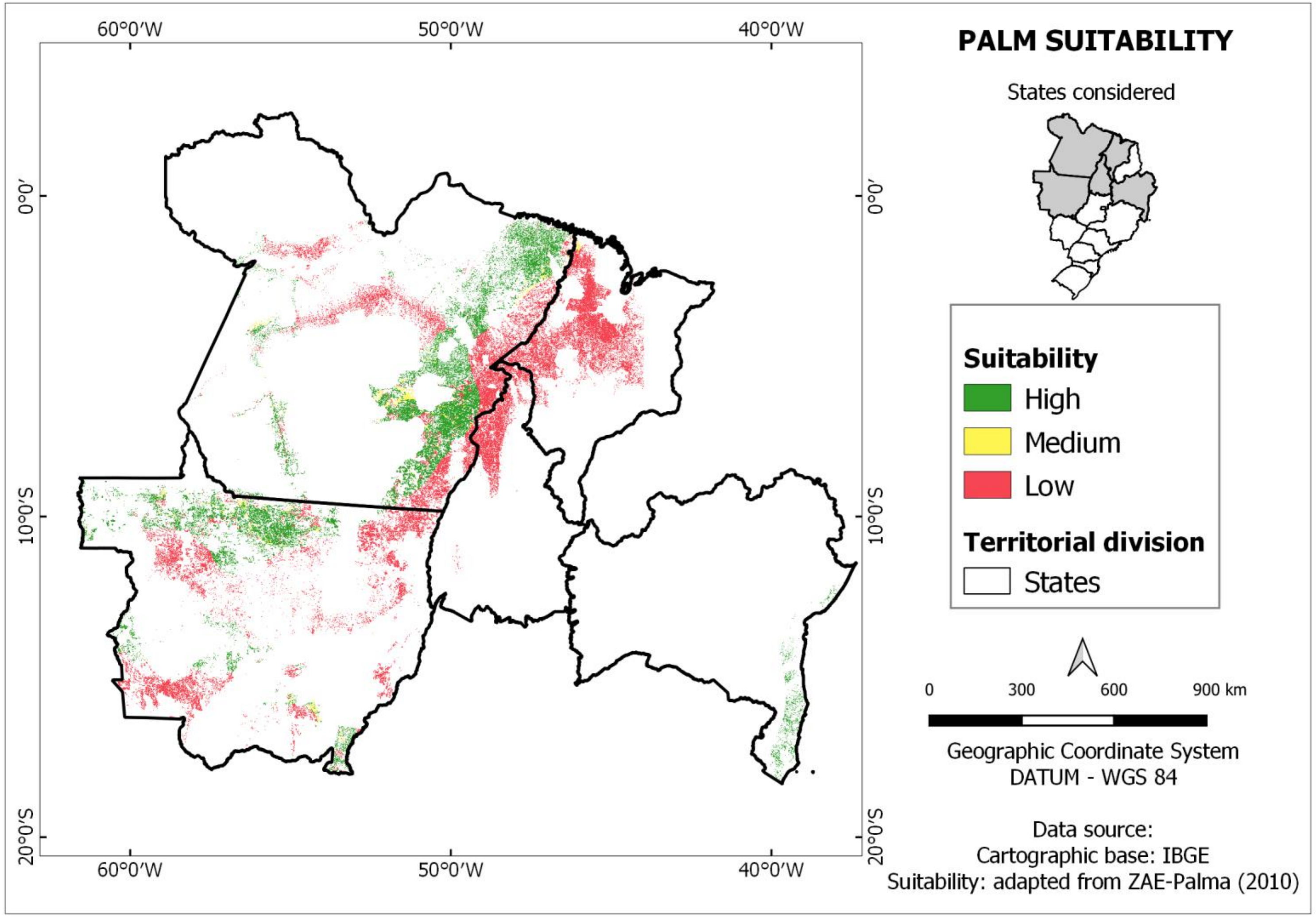
Analysis of the results based on Minimum Selling Prices (MSP), comparing them with those presented in the literature and actual fossil kerosene prices, considering cost reduction opportunities and trends, etc.

Palm suitability (1)



- Here, palm suitability was addressed according to the results of the Agroecology Zoning developed by the Federal Government. The study focused on planting palm in already deforested areas of the Amazon biome (based on a 2008 report), considering the fusion of the South American palm (*Elaeis oleifera*) with the African palm (*Elaeis guineensis Jacq.*) (EMBRAPA, 2010).
- The figure illustrates the main results, with areas classified from “preferential” (the best group for palm cropping) to “unsuitable”.

Palm suitability (2)



- The map corresponds to the result of the combination of the areas classified in the Agroecological Zoning for palm with the areas considered eligible in this project, i.e. sensitive areas (e.g. protected areas, indigenous areas) were excluded and it was assumed that production must occur over pasture areas (in 2018).

- The same zoning methodology was further used to assess suitability in Bahia state (biome Mata Atlantica) (MAPA, 2011). Thus, suitability was assessed in this project for five states (PA, MA, TO, MT and BA).
- The original results for “preferential” and “regular” areas were combined to set the “high” suitability group. “Marginal” classification was translated to “medium suitability”, while “unsuitable” corresponds to “low suitability” in the figure; these areas were not considered in the reported case study.

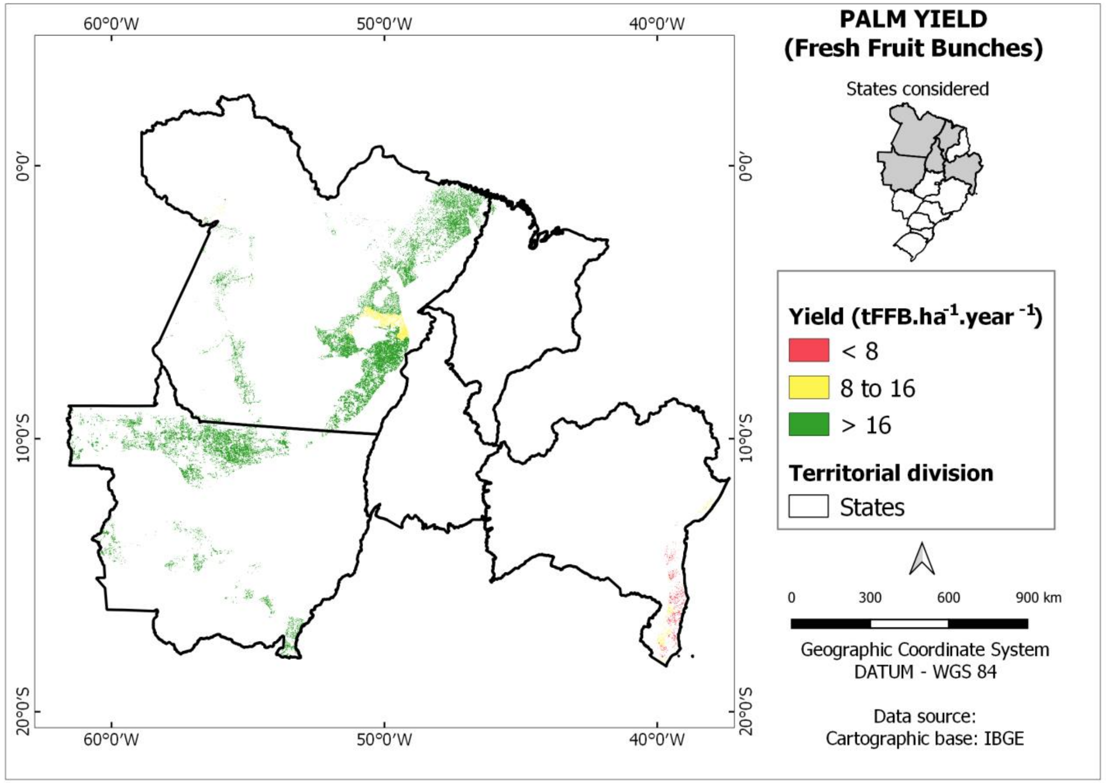
Estimated yields (1)

- The average annual production of palm fresh fruits (FF) along the producing cycle (20 years) was estimated based on a statistical function adjusted to commercial production data of 45 municipalities, in Pará and Bahia. The yield function was defined according to the area harvested, the annual water deficit, the IDP (index related to the rainfall distribution throughout the year) and a dummy variable to differentiate the two states. The correlation coefficient of this function is 90.8%.
- The function was subsequently adjusted to adequately correspond to the reported yield from commercial production in Moju (PA) (Agrianual, 2020) (19.4 $tFF.ha^{-1}.year^{-1}$). The estimated yields for Bahia correspond to the hypothesis that in the future commercial activity could be based on the best practices and on the use of best species; anyhow, the values for Bahia are low compared to Pará (PA) and Mato Grosso (MT).
- In the table below a comparison between actual and predicted yields ($tFF.ha^{-1}.year^{-1}$) is done.

State	Weighted average (2011-2018)[1]	Best results (2011-2018)[1]	Predicted values in the cases studied
BA	16.7	20.1 (2011)	17.6-20.4
MT	No commercial production	No commercial production	17.7-22.0
BA	3.8	4.2 (2017)	6.6-8.8

[1] Values that correspond to actual production.

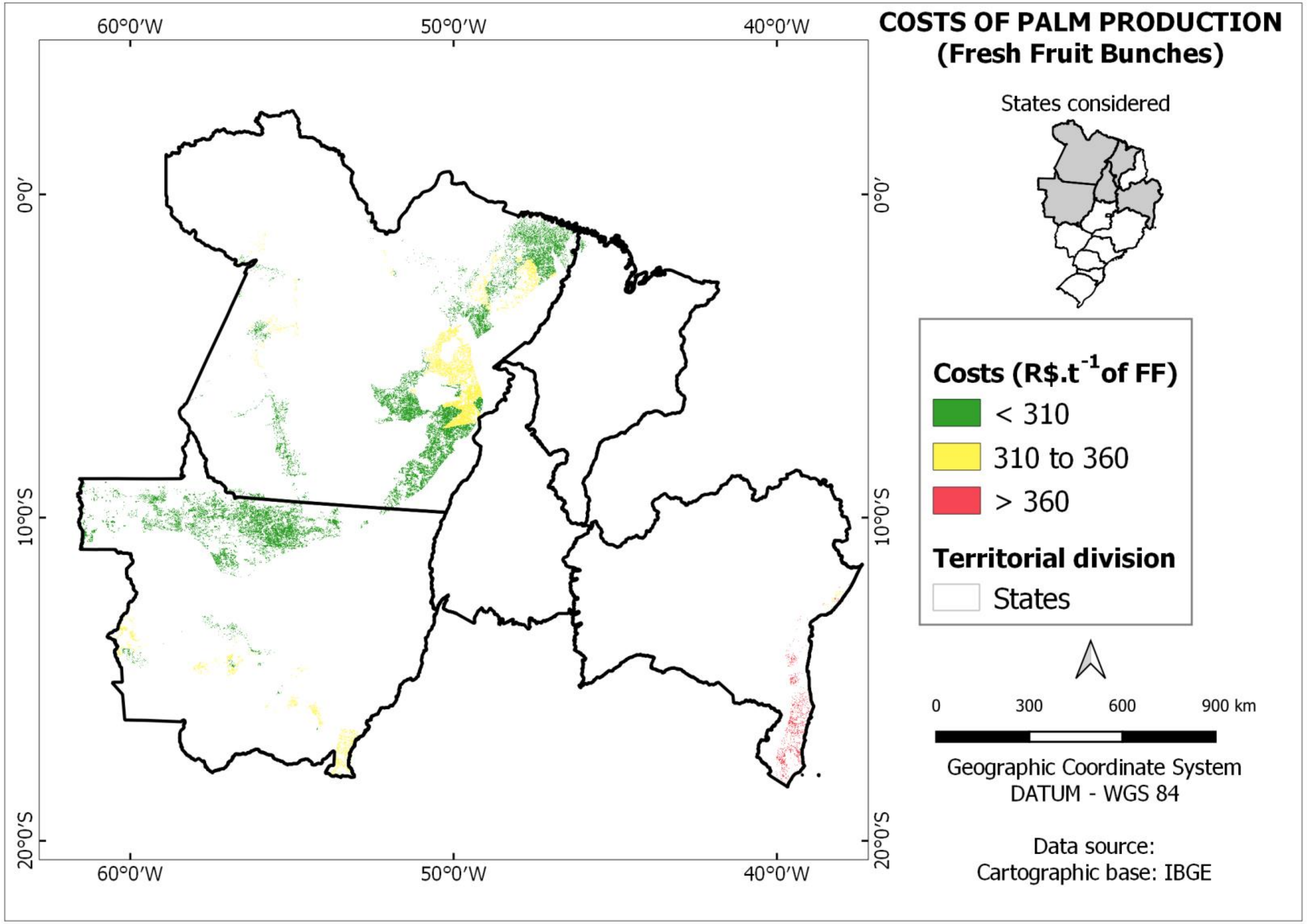
Estimated yields (2)



- The figure above shows the distribution of palm yields (average values for the cycle) in the three states considered in this study. As mentioned, the estimated yields are lower in Bahia in comparison with predicted values for Mato Grosso and Pará.

- Once the production of fresh fruit has been estimated, the next step is to assess palm oil production. The bulk of the literature indicates that palm oil yield (oil from the mesocarp) corresponds to 22% of the weight of the bunch of fresh fruits ($t.tFFB^{-1}$) along the producing cycle (EMBRAPA, 2004; EMBRAPA, 2010; Reis et al. 2017; Semedo, 2002; Silva, 2006), with few publications indicating different figures (e.g. 18-20%) (Silva, 2006). Here, 22% was considered.
- From the estimated yield of fresh fruits, the resulting oil yield would vary between 3.1 and 4.3 $t.ha^{-1}.year^{-1}$ of palm oil, estimate that should be compared with reported results in traditional producing countries: e.g. 3.5 $t.ha^{-1}.year^{-1}$ in Malaysia and 3.9 $t.ha^{-1}.year^{-1}$ in Colombia (Jalani et al. 2002), and varying between 3.8 and 4.1 in Indonesia (Anwar et al., 2014).
- As for the palm kernel oil, the yields reported in the literature vary from 1.5% (Reis et al., 2017) to 3% (Semedo, 2002; MAPA, 2018), with the more common value being 2% (EMBRAPA, 2004; EMBRAPA, 2010).

Costs of palm production



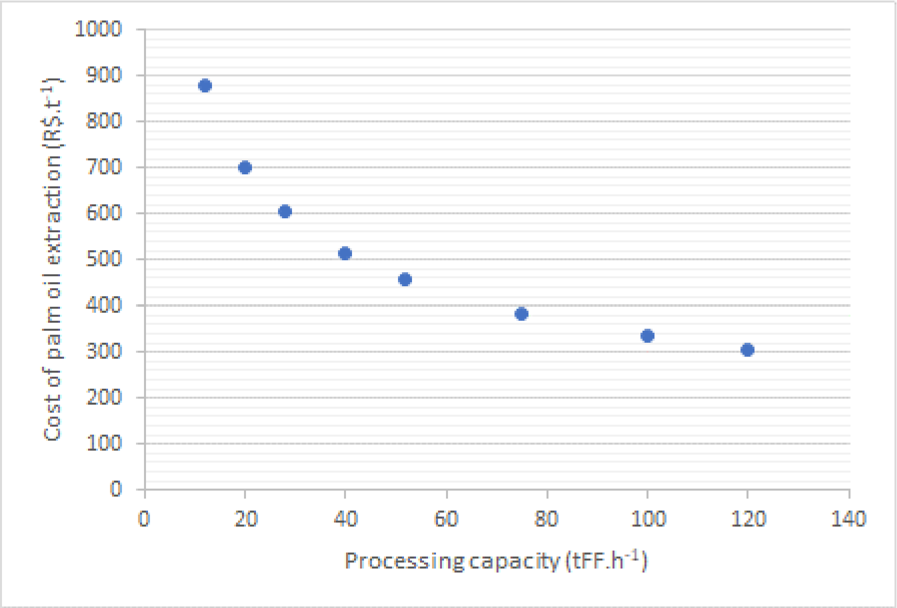
- Due to the variability of costs and yields throughout the production cycle, levelized costs were calculated assuming a discount rate of 8% per year. Costs are mostly impacted by yields, but in some cases the land opportunity cost is also relevant.

- The figure shows the distribution of estimated costs of palm production in the three Brazilian states here considered. Costs are expressed in R$ (2018) per tonne of fresh fruits produced per year (on average, considering the producing cycle).
- Costs were estimated based on Agrianual (2018), which reports the case of commercial production in Moju (PA).
- The costs include the opportunity cost of land, all procedures before planting, manual and mechanized operations, necessary inputs, maintenance and harvesting. See Supplementary Material for details.

Costs of palm oil production

Municipality	State	Production cost (R$.tFF^{-1})[a]	At the extraction unit (R$.tFF^{-1})[b]	Average yield (tFF.year^{-1})[b]	Extraction cost (R$.t oil^{-1})[c]
São Miguel do Guamá	PA	288.24	306.91	20.6	312.61 (9)
Tailândia	PA	292.04	317.22	19.7	331.15 (5)
Xinguara	PA	321.85	327.59	19.0	312.61 (9)
Alto Araguaia	MT	326.96	342.15	17.9	359.78 (3)
Terra Nova do Norte	MT	288.12	307.81	22.0	312.61 (9)
Teixeira de Freitas	BA	491.48	504.15	8.2	397.67 (1)
Barrolândia (Belmonte)	BA	519.30	533.38	7.0	364.53 (1)

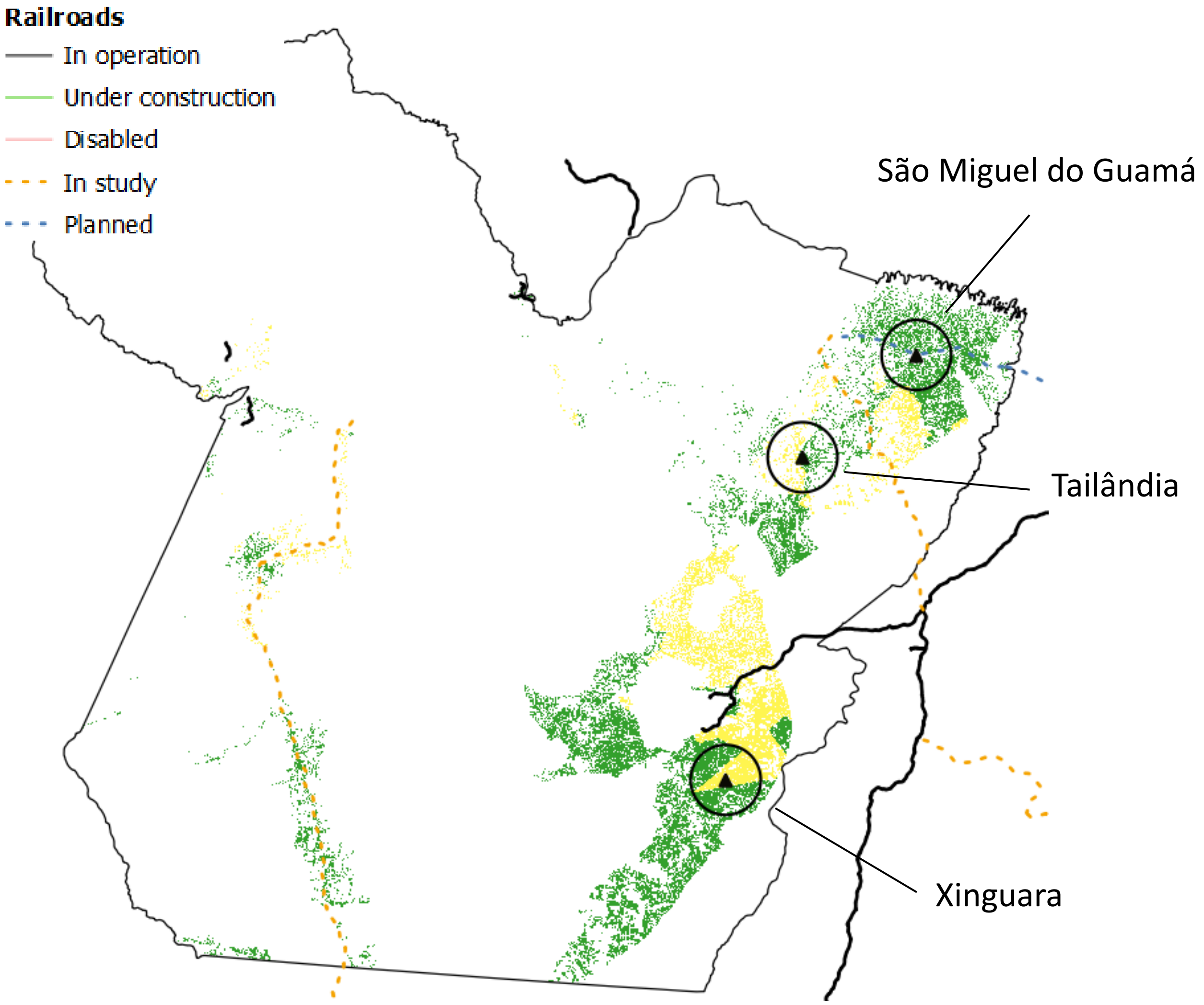
[a] Average estimate for the municipality, as function of predicted yield and land opportunity cost.
[b] Average values for the whole potential production around each locality.
[c] Number of processing units considered, between parentheses.



- The figure shows the estimated costs of palm oil extraction as function of the hourly processing capacity.
- Except the cases of the two sites in Bahia, in all other five cases it was considered multiple extraction units. Currently the largest plant in Brazil has capacity of processing 120 tFF.h^{-1} and this was assumed a limit.

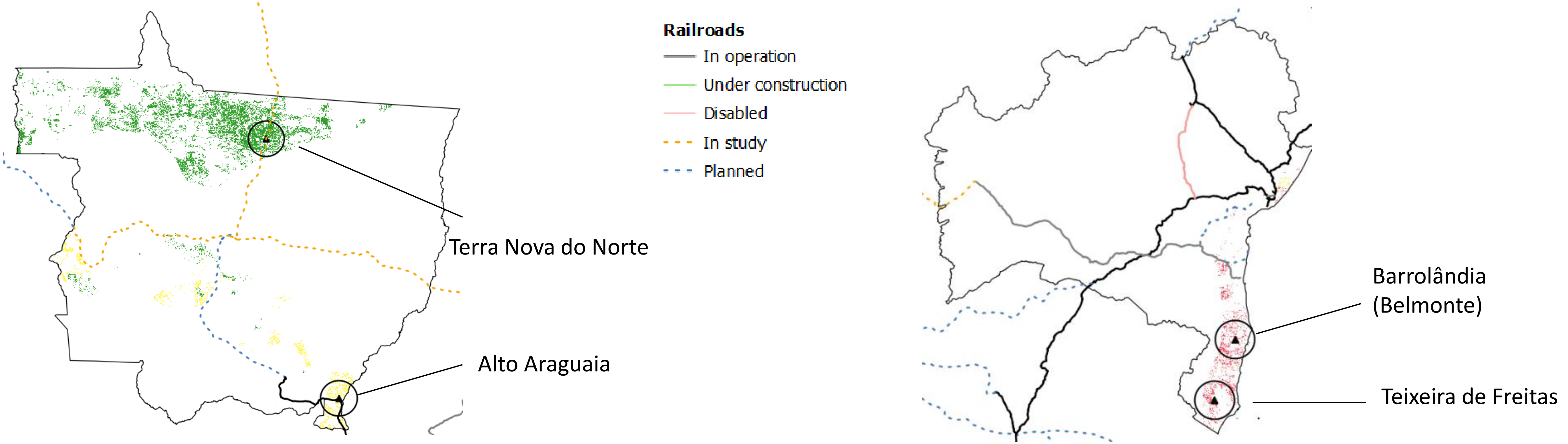
- The cost of palm production was estimated for each pixel. To this estimate it was added the cost of transporting the bunches of fresh fruits to the extraction units, and this adds 1.8% (Xinguara) to 8.6% (Tailândia) to the costs of producing fruits.
- The cost of oil extraction was calculated based on Reis et al. (2017). An assumption is that the revenue from the sale of bran and palm kernel oil should reduce the cost of palm oil. Reis et al. (2017) present the costs of an unit able to process 51.7 tFF.h^{-1}, and scale effects have been considered for other capacities.
- Additional information about extraction units is presented in the Supplementary Material.

Production areas considered: Pará



- The rationale is that palm processing 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 were chosen based on the estimated costs of producing palm (i.e. bunch of fresh fruits), on the potential production, on the proximity to paved roads and railways, and on the existing basic infrastructure (for example, hospitals, schools, etc.).
- The municipalities chosen in Pará were: São Miguel do Guamá, Tailândia and Xinguara. In the first two there is already commercial production of palm.
- The assumption of transporting by railroads is due to the fact that distances are very large to the refineries. However, some railroads do not exist yet and are neither under construction.

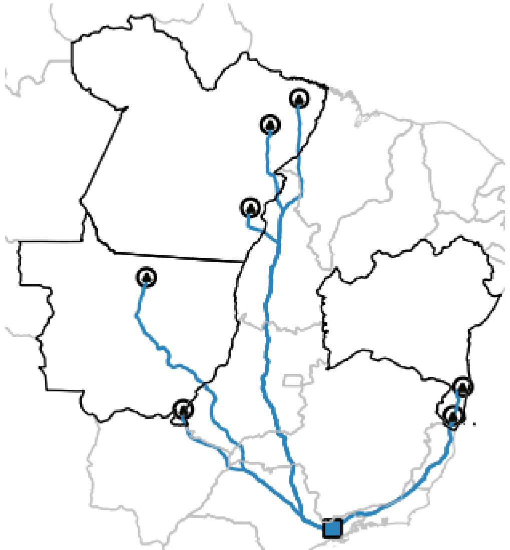
Production areas considered: Mato Grosso and Bahia



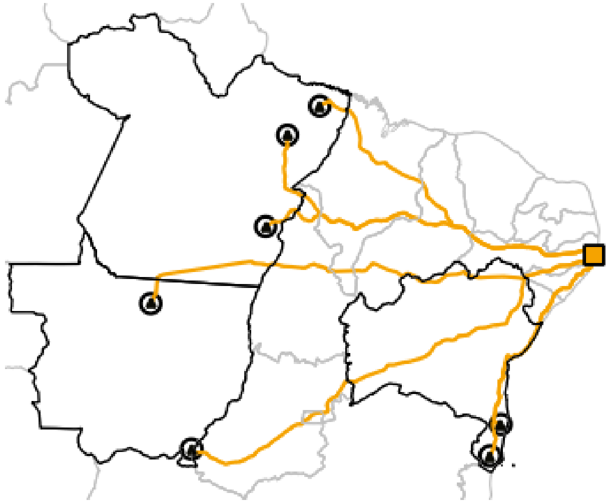
- In Mato Grosso (left side) the municipalities chosen were Terra Nova do Norte and Alto Araguaia. The planned railroads aim to facilitate the transportation of soy.
- In Bahia (right side) the municipalities chosen were Teixeira de Freitas and Belmonte (in this case the processing unit would be in a district - Barrolândia - located west of the city). There are no railroads close to these municipalities.

Road distances to the refineries

REGAP



REVAP

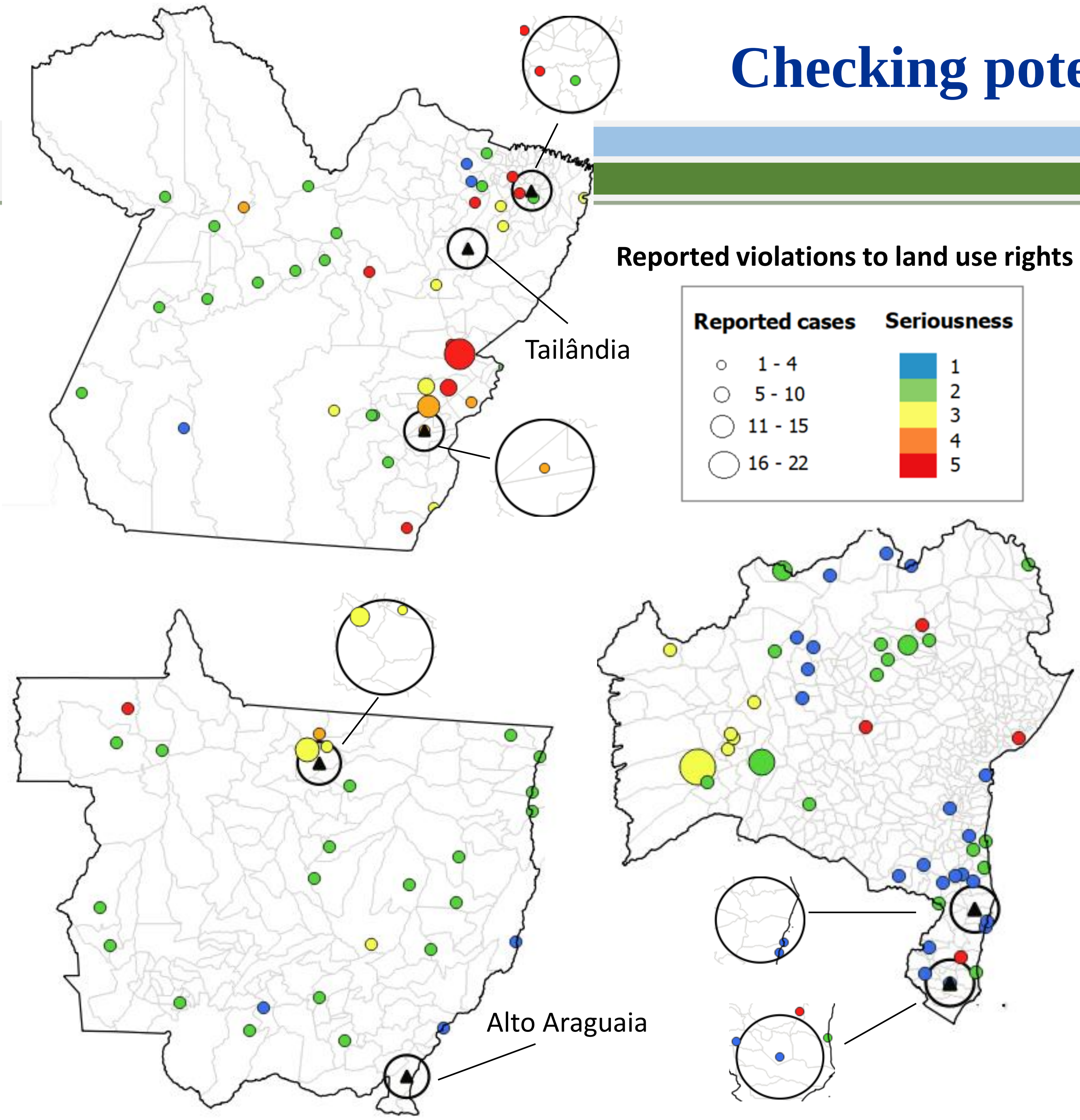


RNEST

Municipality	State	REGAP	REVAP	RNEST
São Miguel do Guamá	PA	2,612	2,880	2,068
Tailândia	PA	2,502	2,767	2,366
Xinguara	PA	2,066	2,337	2,145
Alto Araguaia	MT	1,190	1,239	2,910
Terra Nova do Norte	MT	2,280	2,318	3,065
Teixeira de Freitas	BA	770	1,194	1,528
Barrolândia (Belmonte)	BA	950	1,417	1,375

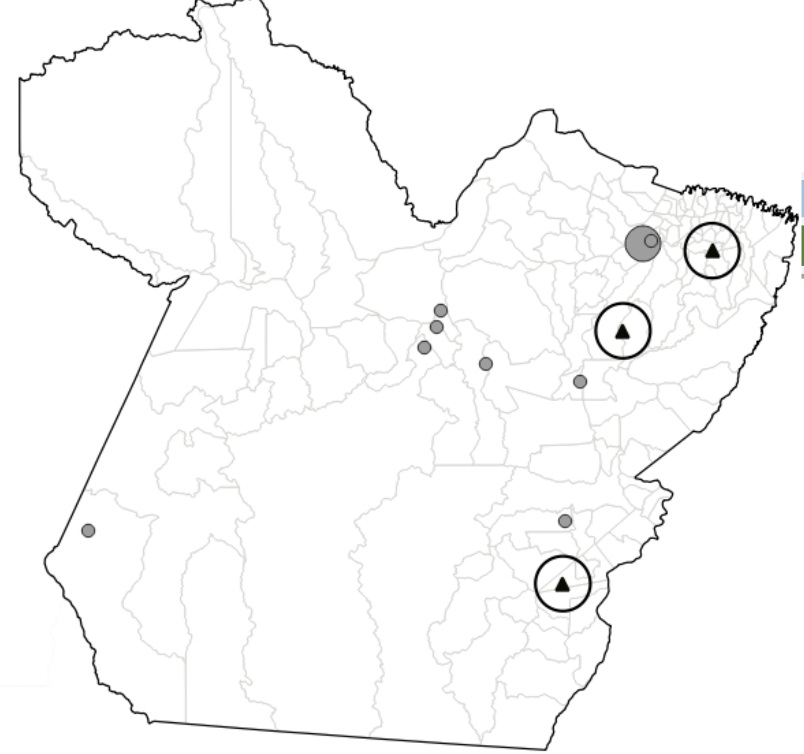
- The figures show the assumed routes – using main paved roads – from each one the seven sites considered to the three oil refineries.
- In the case of Terra Nova do Norte (MT) (see slide with results), transporting palm oil by truck adds 1.8 or 2.2 €.GJ^{-1} to the CIF oil costs at REVAP or RNEST, respectively. In case of São Miguel do Guamá (PA), 2.1 or 1.7 €.GJ^{-1} would be added to the CIF oil costs at REVAP or RNEST, respectively.

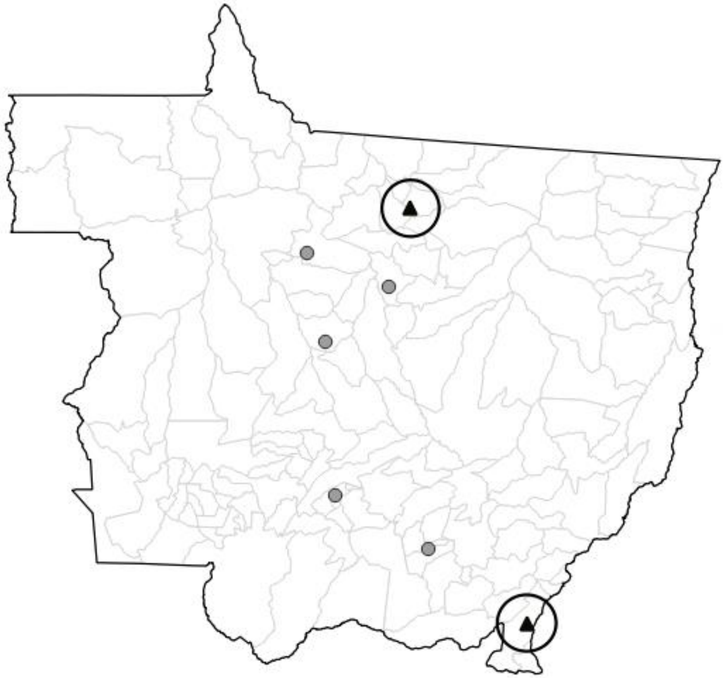
Checking potential constraints (1)



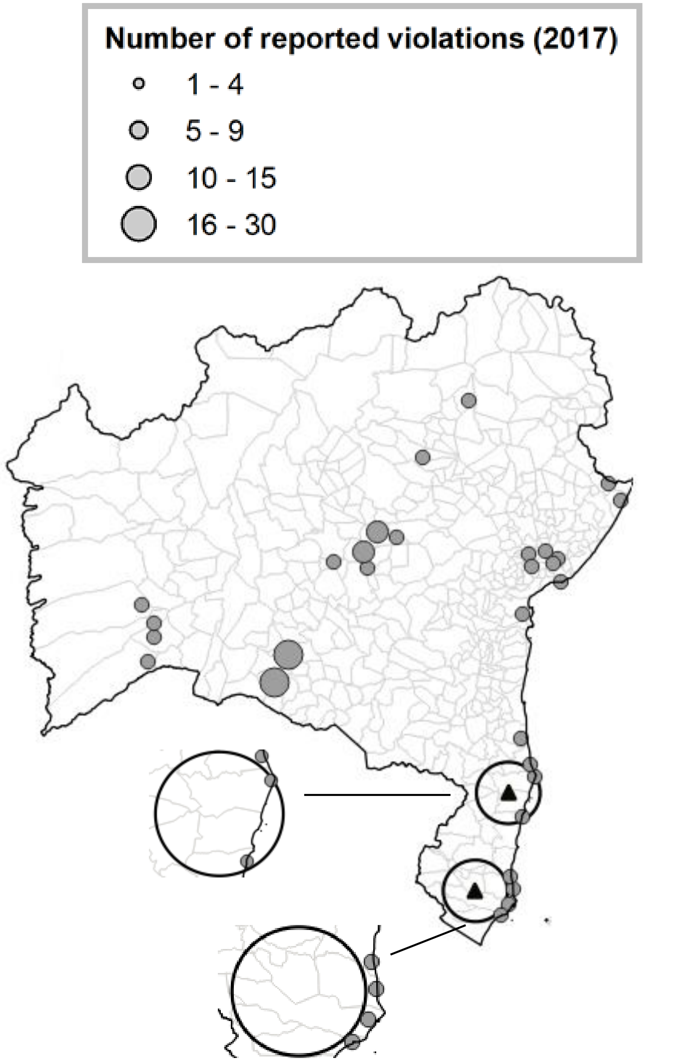
- An additional procedure was the verification of recent reported violations to land use rights and water use rights. Additional information is available in the Supplementary Material.
- It was assumed that investors would take this information into account, aiming to reduce risks. This was not assumed a restrictive aspect, but it must be taken into account in a detailed assessment.
- The figures show the location of the seven sites chosen, and their influence areas. The municipalities marked by colored circles are those with registers of violation to land use rights in recent years.
- It can be seen that out of the seven considered only two sites have no reported cases inside their influence area: Alto Araguaia, in southeast Mato Grosso, and Tailândia, in northeast Pará.

Checking potential constraints (2)





Reported violations to water use rights



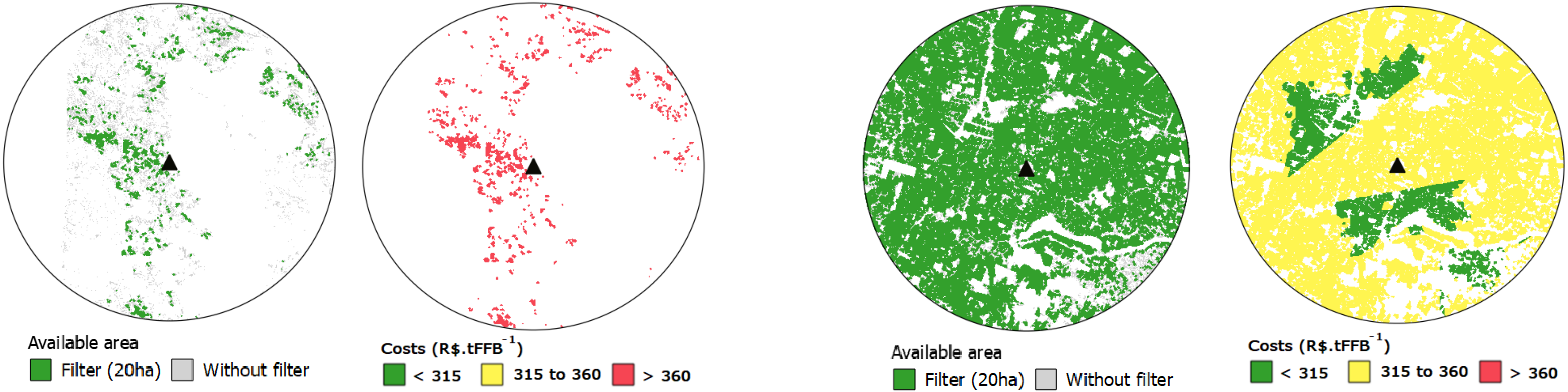
- The figures show the seven municipalities chosen and their influence areas. The municipalities marked by grey circles are those with registers of violation to water use rights in recent years.
- It can be seen that among the seven sites only the two in Bahia state had reported violations in the influence areas, or close to them.
- It was not assumed that violations to water use rights would be a restrictive aspect, but it seems clear that it must be taken into account in a detailed assessment.
- Additional information is available in the Supplementary Material.

Assessing potential palm production / filtering the results (1)

Municipality	State	Area assessed (1,000 hectares)	Area adjusted (1,000 hectares)	Reduction (%)
São Miguel do Guamá	PA	410.90	204.30	50
Tailândia	PA	194.71	110.98	43
Xinguara	PA	639.37	590.65	8
Alto Araguaia	MT	182.54	98.93	46
Terra Nova do Norte	MT	462.53	370.07	20
Teixeira de Freitas	BA	106.96	39.81	63
Barrolândia (Belmonte)	BA	143.15	57.27	60

- In assessing the area available for the production of palm within the influence area, 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 60%, or even more.

Assessing potential palm production / filtering the results (2)



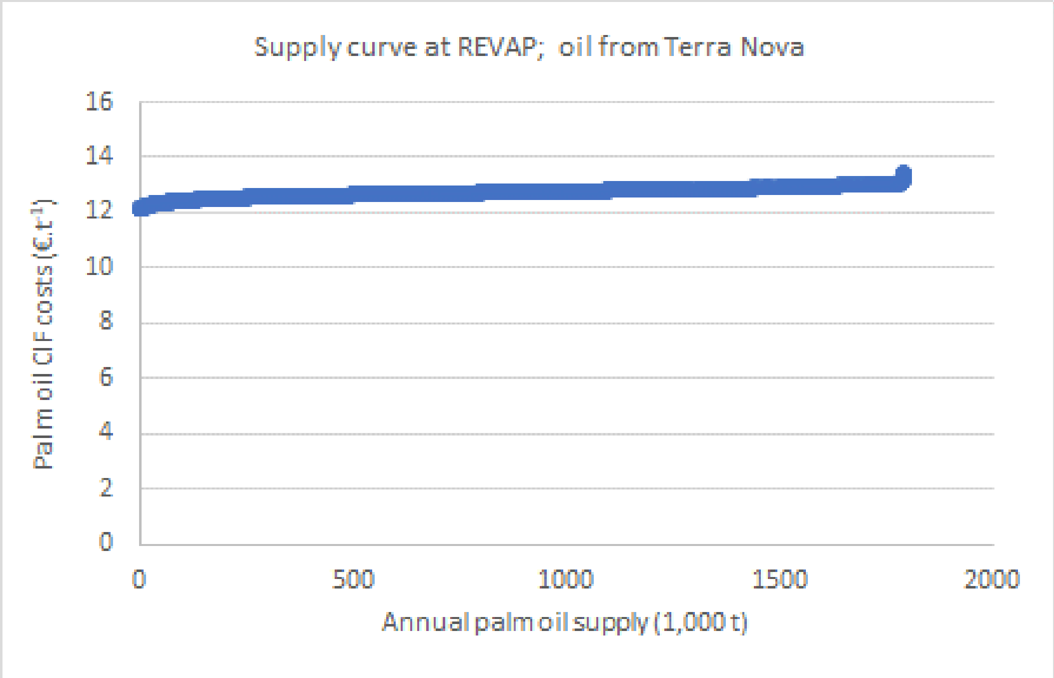
- The figures in the left side are related to Teixeira de Freitas (BA), while those in the right side are for the Xinguara case (PA). Among the seven cases reported here, these figures illustrate, respectively, the largest and the smallest impact due to the filtering procedure.
- In the case of four out the seven cases assessed (the three in PA and one in MT), an important issue that will be further explored is that the Brazilian Forest Act requires private landholders within the Amazon region to set aside 80% of their land as legal reserves for nature protection (Freitas et al., 2018); 35% in Cerrado. Thus a large portion of land must be set aside by private investors, impacting the potential.

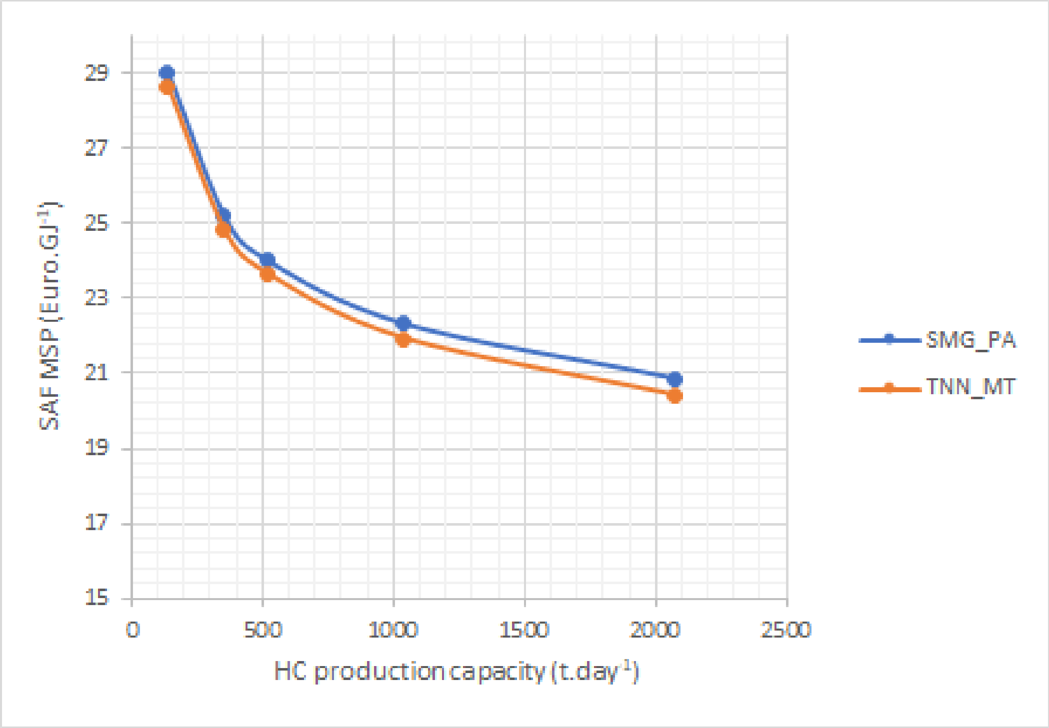
First set of results

Municipality	State	Estimated potential production		CIF costs at (€.GJ^{-1})		
		Fresh fruits (kt.$year^{-1}$)	Oil (kt.$year^{-1}$)	REGAP	REVAP	RNEST
São Miguel do Guamá	PA	4,171.65	917.76	12.82	12.95	12.52
Tailândia	PA	2,187.06	481.15	13.19	13.32	13,11
Xinguara	PA	11,290.61	2,483.93	13.12	13.27	13.16
Alto Araguaia	MT	1,761.70	387.57	13.31	13.34	14.29
Terra Nova do Norte	MT	8,134.40	1,789.57	12.66	12.69	13.07
Teixeira de Freitas	BA	325.59	71.63	17.93	18.23	18.44
Barrolândia (Belmonte)	BA	410.96	90.41	18.91	19.22	19.19

- For both municipalities there is a small advantage for the production at REGAP, comparing with the production at REVAP, but in order to keep the coherence with the previous study for macaw oil, the detailed assessment was done considering the production of SAF at REVAP and RNEST.

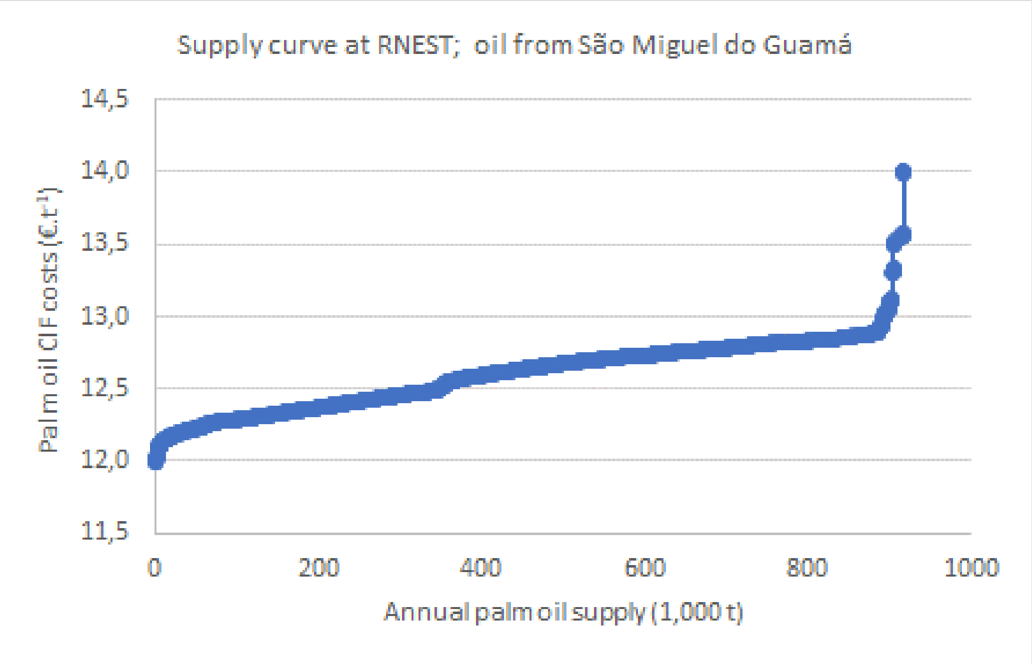
- For the seven producing areas studied the preliminary results of the assessment are presented in the table: the annual estimated total production of fresh fruits (average for the whole cycle) and palm oil (oil from pulp), besides average CIF costs of oil at the three refineries considered (oil transported by trucks).
- Based on these results, and knowing the required palm oil demand for each industrial capacity, two cases were evaluated in details: feedstock production exclusively in São Miguel do Guamá (PA) and Terra Nova do Norte (MT).

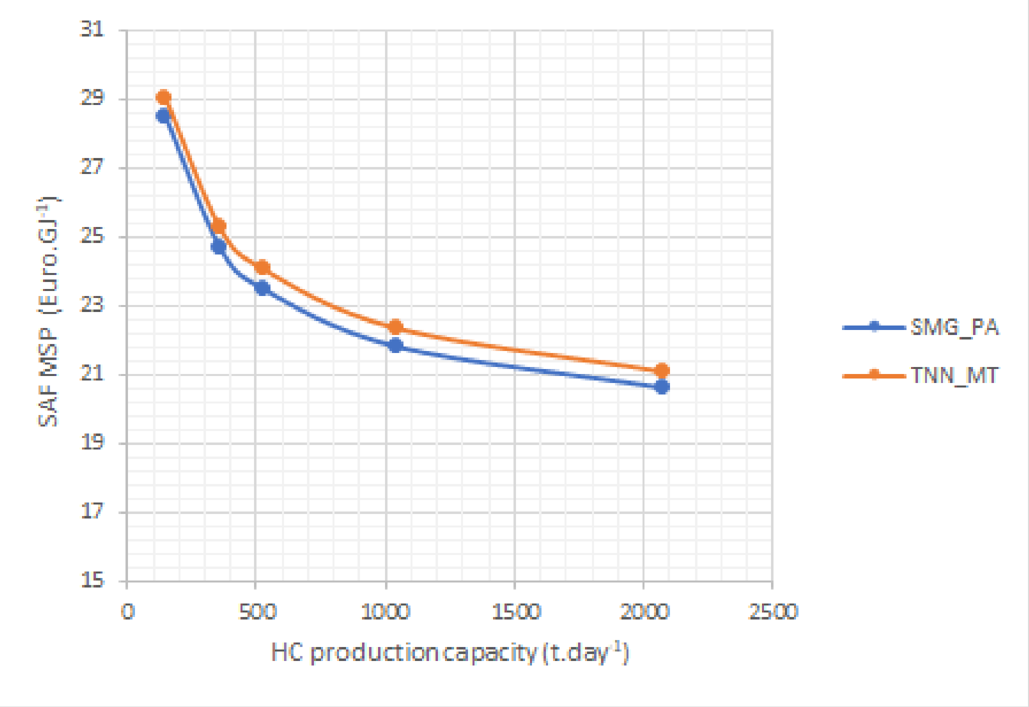




SAF production at REVAP

- The upper figure shows the palm oil supply curve from Terra Nova do Norte (MT), 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 Terra Nova do Norte (TNN) or São Miguel do Guamá (SMG).
- Five capacities were considered and in all cases there is a small advantage for the supply from Terra Nova (for the largest capacity – 2,075 $t.day^{-1}$ – the difference is 2.2%; for the smallest industrial capacity the difference in MSP is 1.3%).
- The lowest MSP would be 20.4 $€.GJ^{-1}$ for the production of 2,075 t of hydrocarbons per day (300.1 $t.day^{-1}$ of SAF).





SAF production at RNEST

- Upper figure shows the palm oil supply curve from São Miguel do Guamá (PA), 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 (São Miguel do Guamá – SMG and Terra Nova do Norte - TNN).
- There is a small advantage of producing with palm oil from São Miguel do Guamá: 2.0%-2.5% lower MSP compared to the alternative supply.
- The lowest MSP would be 20.6 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF).
- Thus, the results related to the production at RNEST are quite similar to the results of producing at REVAP (previous analysis), but counting on a different supplier source.

Considering the level of soil degradation in pasturelands (1)

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
São Miguel do Guamá	PA	93.6	4.2	1.5	0.7
Tailândia	PA	74.2	12.2	6.4	7.2
Xinguara	PA	40.9	24.8	20.2	14.1
Alto Araguaia	MT	24.5	22.4	22.8	30.2
Terra Nova do Norte	MT	25.5	21.5	23.8	29.3
Teixeira de Freitas	BA	76.6	15.3	5.0	3.1
Barrolândia (Belmonte)	BA	86.8	8.2	2.9	2.1

- 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 palm only on degraded pasturelands, both in Terra Nova do Norte and in São Miguel do Guamá.
- 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.

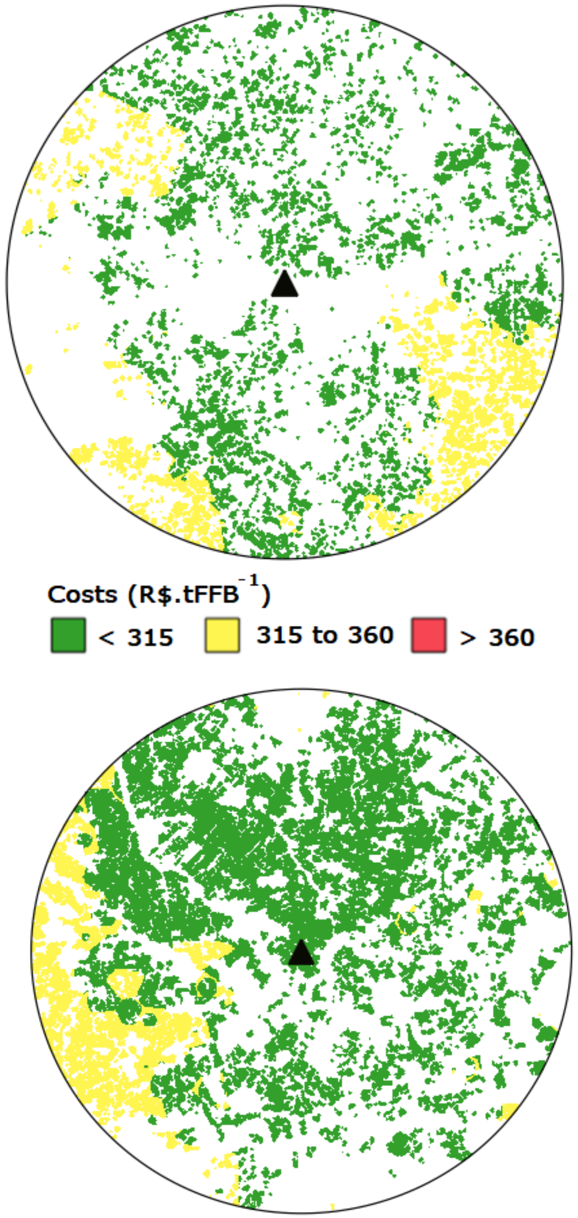
Considering the level of soil degradation in pasturelands (2)

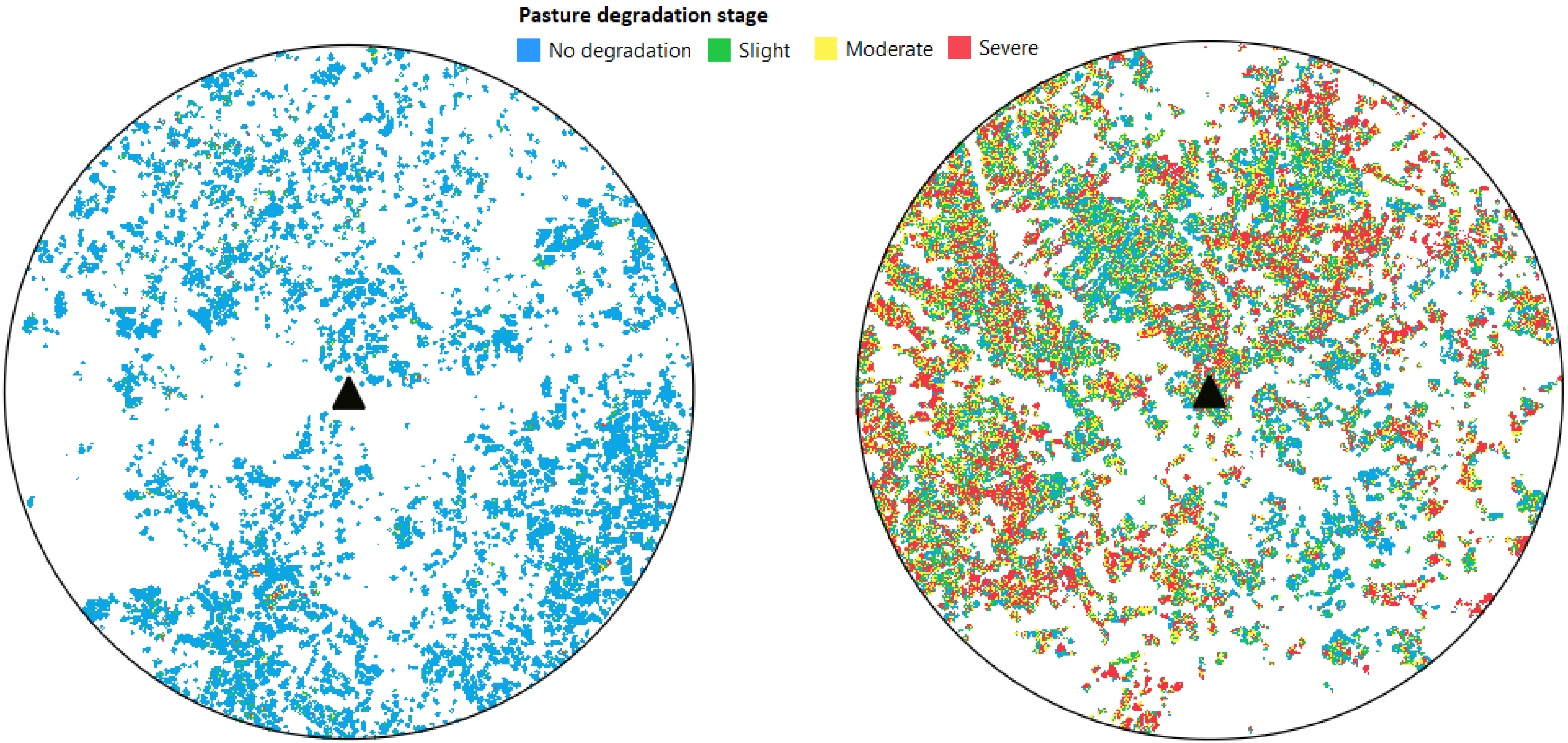
Municipality	State	No degradation	Some level of degradation
São Miguel do Guamá	PA	168,364	11,544
Tailândia	PA	73,264	25,472
Xinguara	PA	221,040	319,032
Alto Araguaia	MT	20,776	64,000
Terra Nova do Norte	MT	85,164	249,180
Teixeira de Freitas	BA	27,004	8,228
Barrolândia (Belmonte)	BA	44,072	6,680

- The hypothesis assumed is that the soil would be recovered before the beginning of the palm 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 palm oil but, on the other hand, the start of its cycle would be delayed.

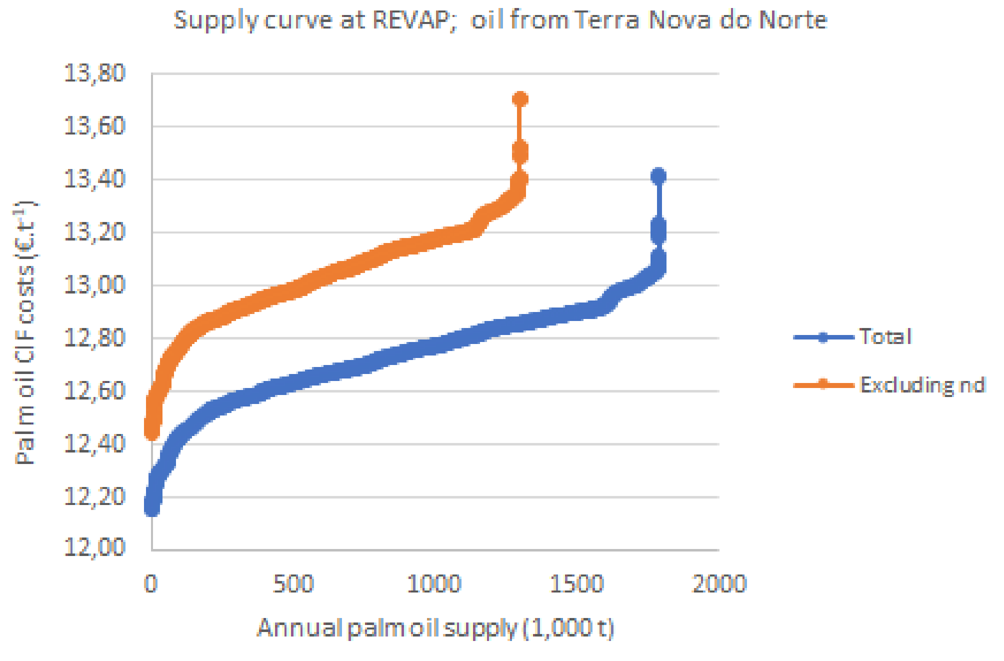
- The table shows the estimated areas, in hectares, of non-degraded and degraded – at some level – pasturelands in the seven sites considered in this assessment.
- From this table and the previous one it can be concluded that pasturelands are more degraded in south of Pará and in Mato Grosso.
- In the north of Pará and in south of Bahia the level of degradation in pasturelands is low, but in Bahia the potential for palm production is low (comparatively, very low yields).
- In this sense, it seems that if the priority is producing in recovered pasturelands, it would be better to prioritize Mato Grosso.

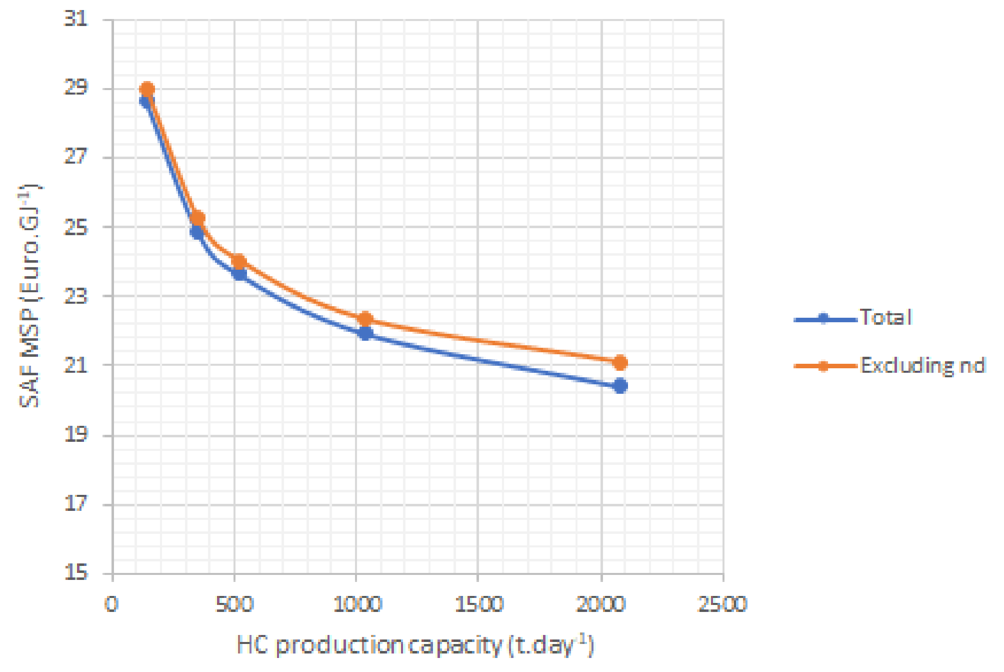
Considering the level of soil degradation in pasturelands (3)





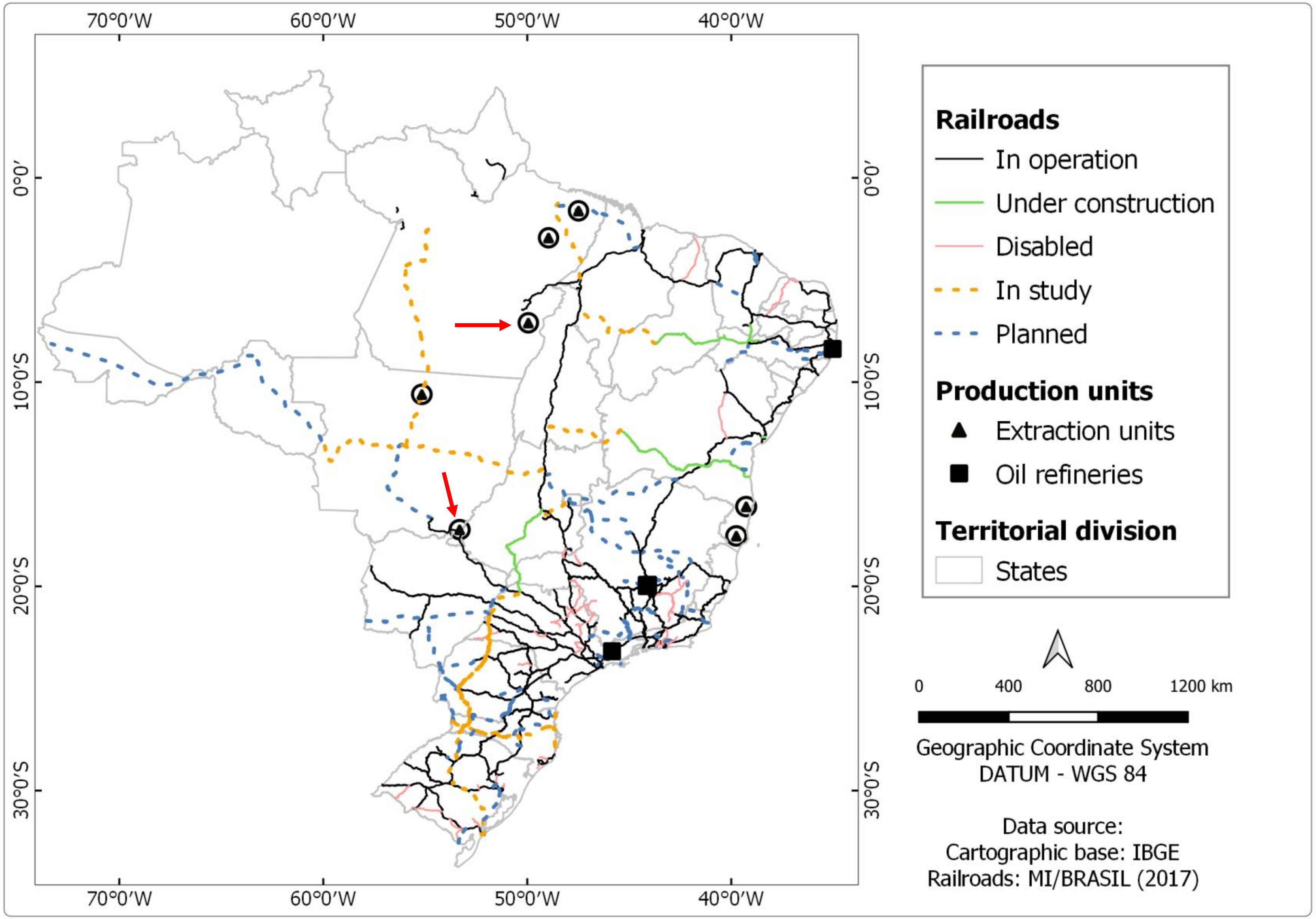
- Left side, on the top, figure for the estimated production costs of fresh fruits around São Miguel do Guamá (PA); on the bottom, the estimated costs around Terra Nova do Norte (MT).
- Top figures: left side, distribution of no-degraded and degraded (at some level) pasturelands around São Miguel do Guamá; right side, the same for Terra Nova do Norte.





SAF production at REVAP – excluding non-degraded pasturelands

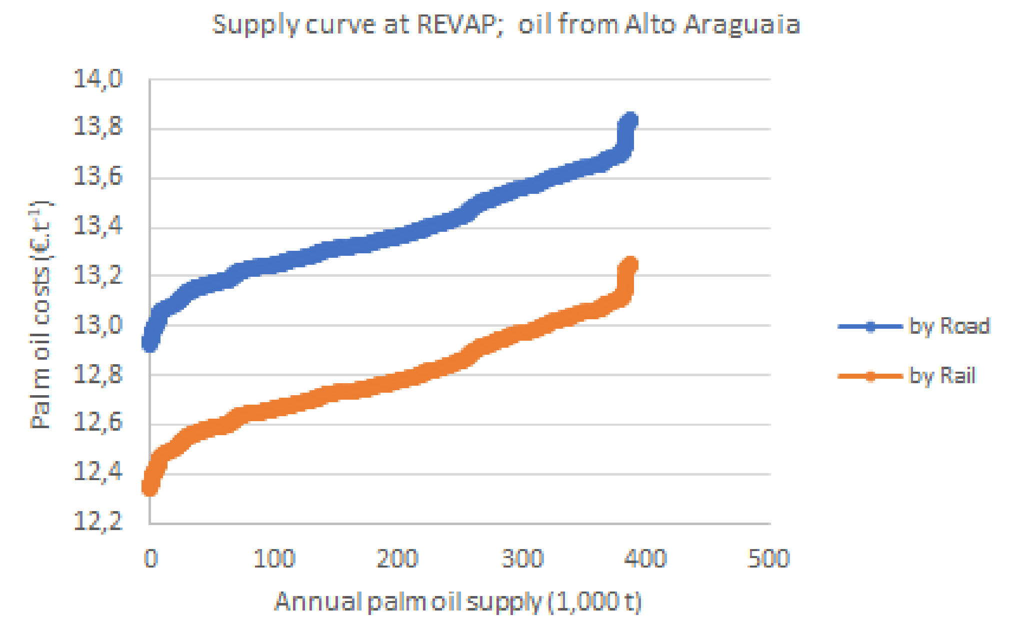
- Upper figure shows the palm oil supply curves at REVAP (only from Terra Nova do Norte – MT), comparing total supply and the results when only degraded pasturelands (at some level) are considered.
- Lower figure shows the estimated MSP of SAF as function of the daily capacity of hydrocarbons production, assuming exclusive supply from Terra Nova in both cases (i.e. no restrictions and production only on degraded pasturelands).
- In the restricted case the potential palm oil supply from Terra Nova would be reduced by about 30%, also with an impact on average CIF costs (from 12.7 to 12.9 €.GJ^{-1}).
- The MSP of SAF passes from 20.4 €.GJ^{-1} to 21.1 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF).
- In the case of São Miguel do Guamá the same strategy makes no sense, since the potential supply is reduced to much less than 10% (from 917.8 t of per year to 54.9 t.year^{-1}).

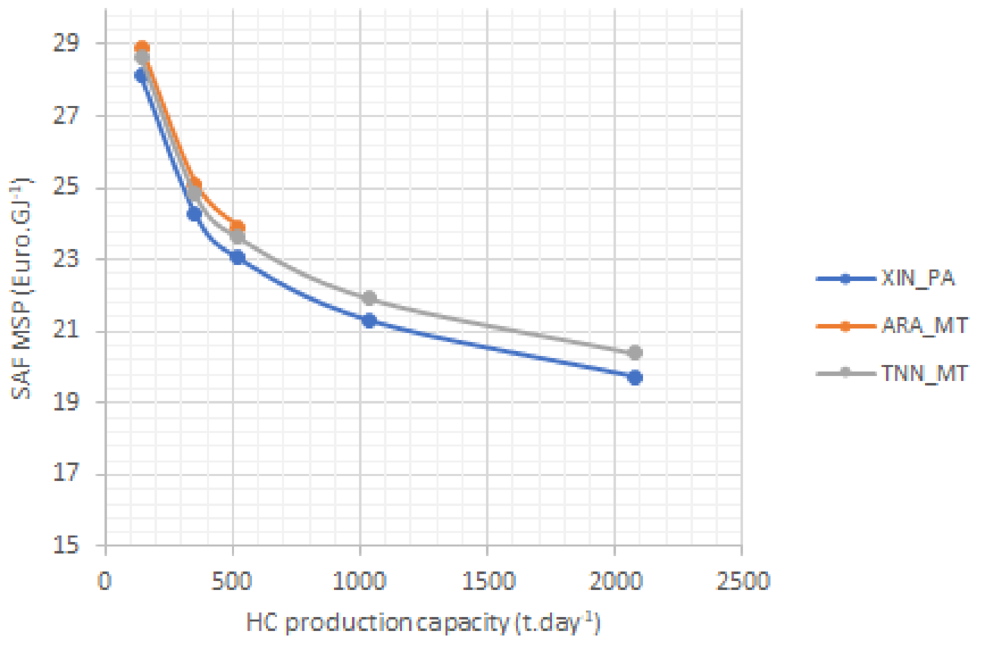


Oil transport by rail

- The figure shows more details about the existing rail network in Brazil in 2017. The information available is th7t the railways that were under construction at the time are not yet in operation.
- In principle it would make sense to consider production and oil transportation by rail from Xinguara (southeast of Pará) and Alto Araguaia (south of Mato Grosso) (indicated by red arrows).
- The cases of transporting palm oil by rail from São Miguel de Guamá (PA) and Terra Nova do Norte (MT) were explored in the sensitive analysis of results.

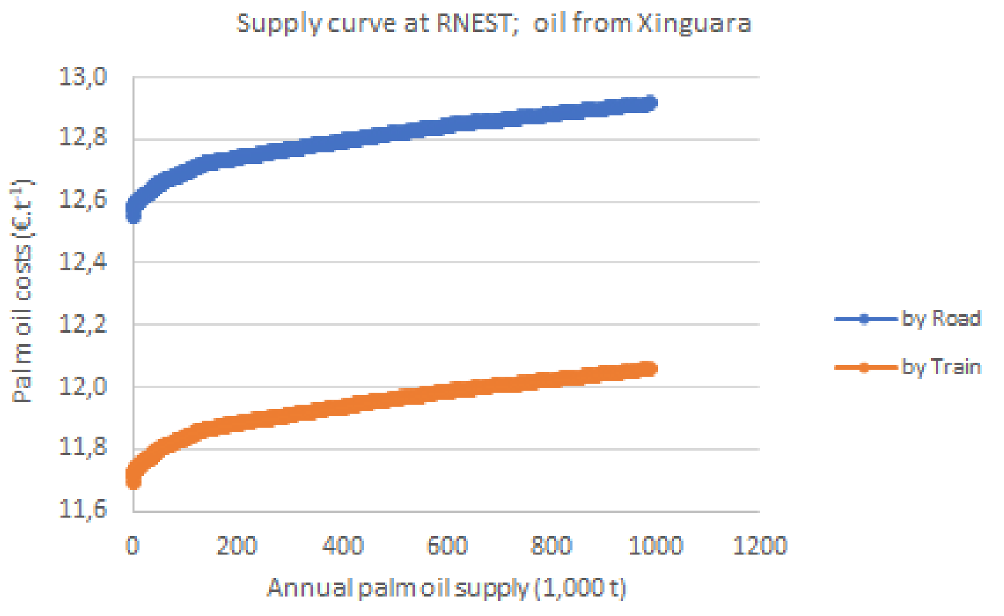
SAF production at REVAP / effect of railroads

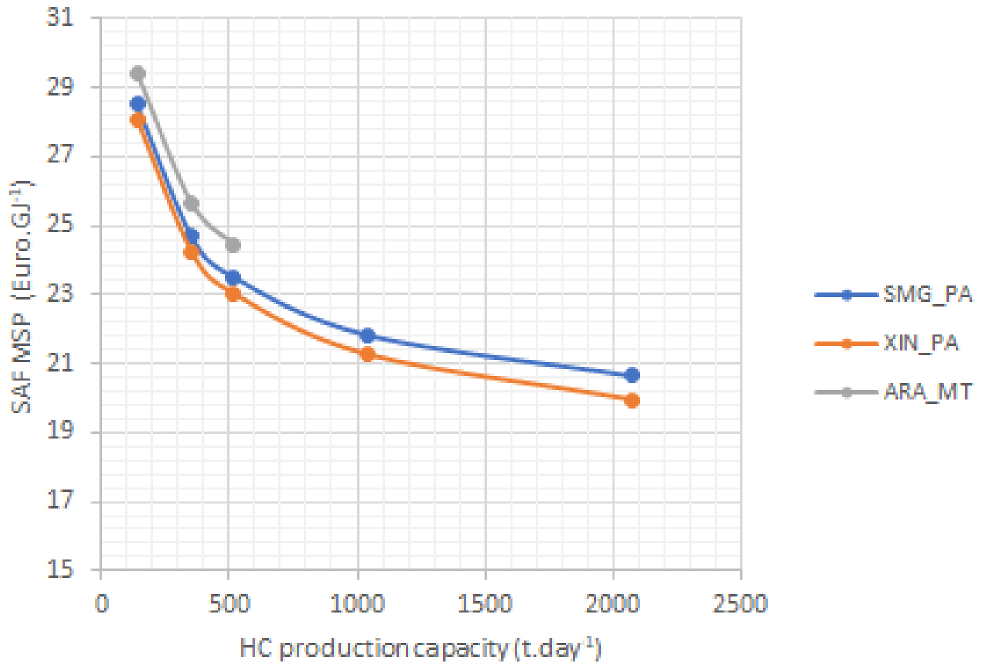




- Considering the production at REVAP exclusively from the palm oil supplied from one single site, what is compared here is the production from Terra Nova do Norte (MT), being the oil transported by trucks (result previously presented), with the supply from Xinguara (PA) and Alto Araguaia (MT), being in both cases the oil mainly transported by train.
- The hypotheses are that the distances would be equal in the case of transporting by truck or train, and that transport costs would be cut in half (see Supplementary Material).
- The upper figure shows the palm oil supply curve from Alto Araguaia (MT), at REVAP, transporting it by road or by trucks. The average CIF costs could be reduced from 13.21 to 12.62 €.GJ^{-1}; the supply is constrained, and there is no oil to feed the largest industrial units.
- Lower figure shows the estimated SAF MSP, comparing the best result previously presented – the oil supply from Terra Nova do Norte (MT) – with the two cases here addressed. It is clear that it would be better to supply oil from Xinguara, supposing it would be possible to transport by train.
- The lowest MSP would be 19.7 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF).

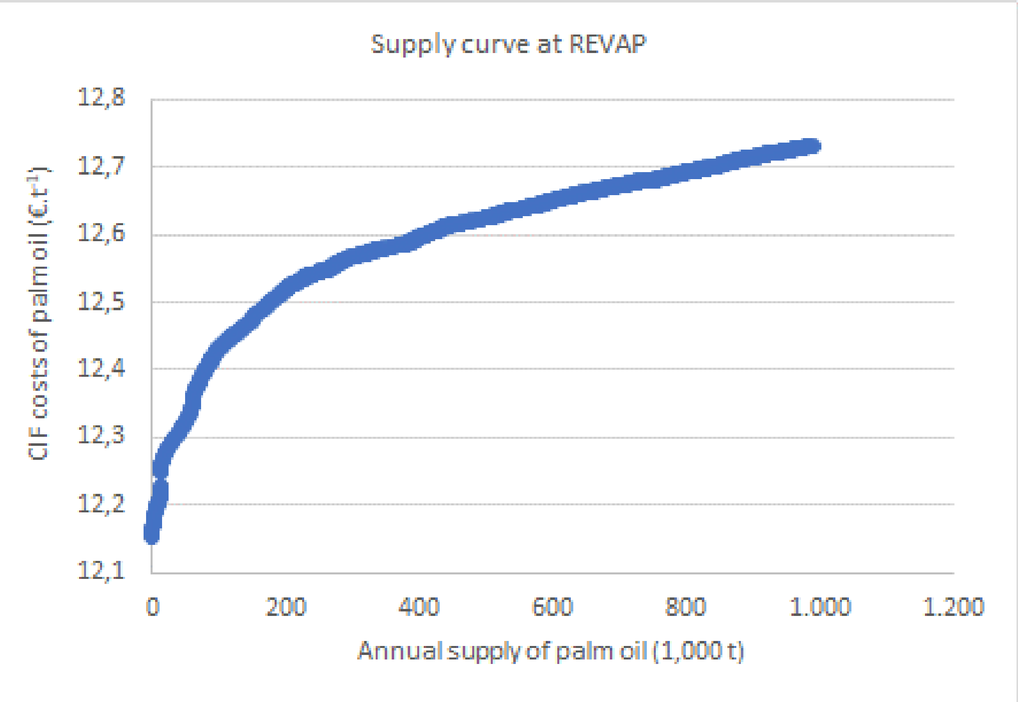
SAF production at RNEST / effect of railroads





- The same has been done considering the production at RNEST. The best result previously presented was for the palm oil supply exclusively from São Miguel do Guamá (PA), being the oil transported by trucks. The alternatives are the supply from Xinguara (PA) and Alto Araguaia (MT), being in both cases the oil mainly transported by train.
- Once more, the hypotheses are that the distances would be equal in the case of transporting by truck or train, and that transport costs would be cut in half (see Supplementary Material). The consideration of same seems to be optimistic when the destination is RNEST.
- The upper figure shows the palm oil supply curve from Xinguara (PA), at RNEST, transporting it by road or by trucks. The average CIF costs could be reduced from 12.75 to 11.89 €.GJ^{-1}.
- Lower figure shows the estimated SAF MSP, comparing the best result previously presented – oil supply from São Miguel do Guamá (PA) – with the two cases here addressed. It is clear that it would be better to supply oil from Xinguara, supposing it would be possible to transport by train.
- The lowest MSP would be 19.9 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF).

Combined supply of palm oil



Municipality	State	Supply @ REVAP	Supply @ RNEST
São Miguel do Guamá	PA	11.9%	62.2%
Tailândia	PA	0.8%	12.3%
Xinguara	PA	2.9%	19.5%
Terra Nova do Norte	MT	84.7%	6.1%

- The figure shows, as an illustration, the combined palm oil supply curve at REVAP for 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). The average CIF cost is 12.58 €.GJ^{-1}, with a tiny impact compared to the CIF costs of the best supply option at REVAP (Terra Nova do Norte – MT).
- Also in the case of RNEST, the impact of combined supply on SAF's estimated MSP is irrelevant. Obviously, despite the irrelevant economic impact, it would be important to diversify the supply from the security point of view.
- The table shows the best supply options considering the combined supply of palm oil at REVAP and RNEST. In both cases, the supplies from Alto Araguaia (MT) and from the two sites in Bahia are not competitive. In the case of REVAP, the contributions of Tailândia and Xinguara can be disregarded.

Analysis of the set of results (1)

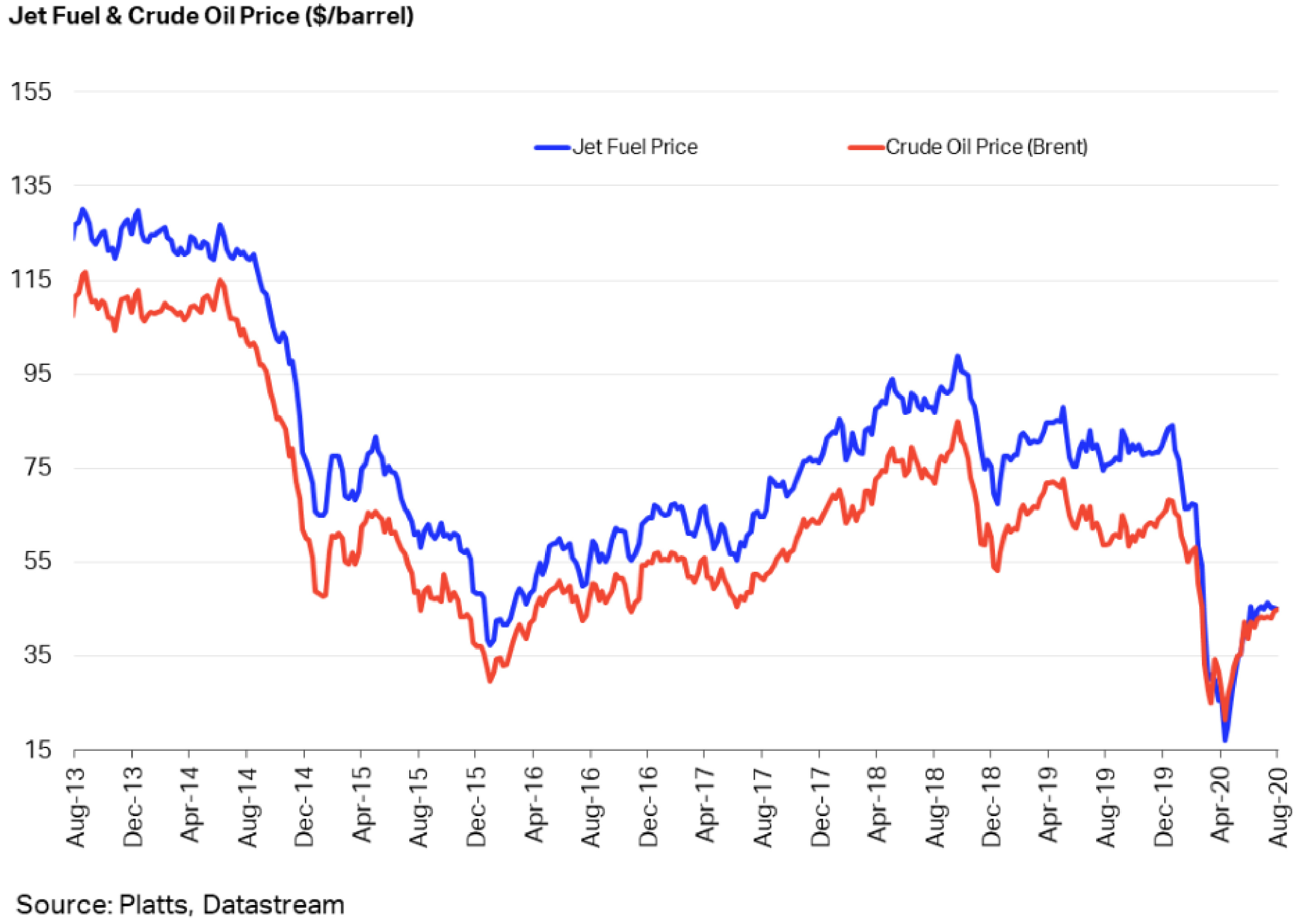
- Table summarizes the economic results of the studied cases.
- Due to scale effects, these are the lowest MSP in each case.
- The production in one unit with the largest industrial plant considered ($300.1\ t.day^{-1}$, or 122.6 million litres of SAF per year) corresponds to 3% of the national consumption of jet fuel in 2018.

Production at	MSP ($€.t^{-1}$)	MSP ($€.GJ^{-1}$)	Case	Production size
REVAP	873.4	20.4	Terra Nova/no restriction[1]	$300.1\ t.day^{-1}$
REVAP	903.2	21.1	Terra Nova/degraded land[2]	$300.1\ t.day^{-1}$
RNEST	883.5	20.6	São Miguel/no restriction[1]	$300.1\ t.day^{-1}$
RNEST	853.2	19.9	Xinguara/transport by train[3]	$300.1\ t.day^{-1}$
REVAP	845.0	19.7	Xinguara/transport by train[3]	$300.1\ t.day^{-1}$
RNEST	883.5	20.6	Combined supply[4]	$300.1\ t.day^{-1}$

[1] Supply site/no restriction on land use;
[2] Supply site/only considering production in degraded pasturelands;
[3] Supply site/palm oil transported by train;
[4] Combined supply from four sites.

- MSP results should be compared to 29 $€.GJ^{-1}$ (1,241 $€.t^{-1}$), which is the value presented by de Jong et al. (2015) assuming the production based on the 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), but in August 2020 the jet fuel price was close to 300 $€.t^{-1}$ due to the low international oil price.

Comparing MSPs with jet fuel prices



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

- Jet fuel market prices is extremely correlated with international oil prices. In the palm oil cases studies, the strict parity of SAF (see previous slide) with fossil jet fuel would require an international oil price close to 120-130 US$.barrel^{-1}.
- 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).

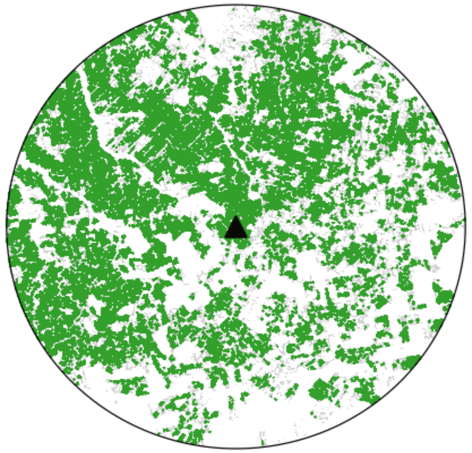
Analysis of the set of results (2)

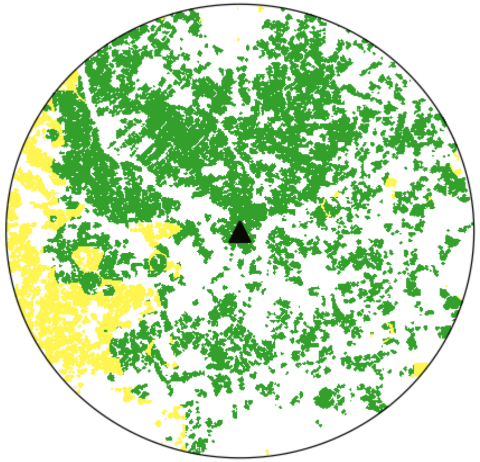
- From an economic point of view, the conclusion is that the production of SAF via HEFA-SPK, from palm oil, will not be feasible unless there is a conjunction of factors, such high oil prices (above 120 US$.barrel^{-1}), palm production in the sites of highest yields, gains in scale in oil extraction, reduction of transportation costs, and gains of scale in SAF production.
- It is unreasonable to consider better SAF feasibility only due to significantly higher yields of palm oil once assumed yields are very close to - or are even higher than - the average of the main producing countries.
- A clear constraint in Brazil is that the best palm potential is pretty much in regions with lack of infrastructure and distant from oil refineries. In this sense, it would be convenient to consider SAF production in Pará state, depending on the availability of natural gas for producing hydrogen, and/or the transport of palm oil to the industrial plant by train or vessels.
- Although palm oil production is commercial in Brazil, an additional constraint is that the required supply - even for a relatively small SAF production - would be significantly greater than the historic results: to feed the largest industrial unit considered here it would be necessary to produce almost three times more fresh bunches than what was produced in 2018.

Analysis of the set of results (3)

- Based on the assumptions done, the palm oil CIF cost represents 69% of the MSP of SAF in case of the largest industrial plants (300 $t.day^{-1}$ of SAF). This result is for the production at REVAP, based on the supply from Terra Nova do Norte (MT) (MSP equal to 20.4 $€.MJ^{-1}$).
- Also in this case, the cost of producing fresh fruit represents 66% of the CIF cost of palm oil at REVAP (excluding opportunity cost of land), while oil extraction represents 16% of the CIF cost and the transport of oil by trucks another 15% (see Complementary Material). In this case, the opportunity cost of the land corresponds to about 3% of the cost of palm oil. The cost of extracting the oil depends on the scale of the processing unit and would be higher if smaller units are considered.
- Transporting fresh fruit to the extraction unit has no significant impact on the cost of oil (about 1% in the case mentioned above), but the location of the processing unit is important due to two aspects. First, the lack of good roads in the countryside of Pará and Mato Grosso and, second, due to the required infrastructure for the processing unit (e.g. supply of utilities).
- The best solution seems to be to combine supply locations, i.e. different production regions should be considered. However, as the palm yield significantly impacts the final result, and the location of the palm processing units (which needs to be very close to the planting areas) is also a crucial aspect, the selection of production sites must be judicious.

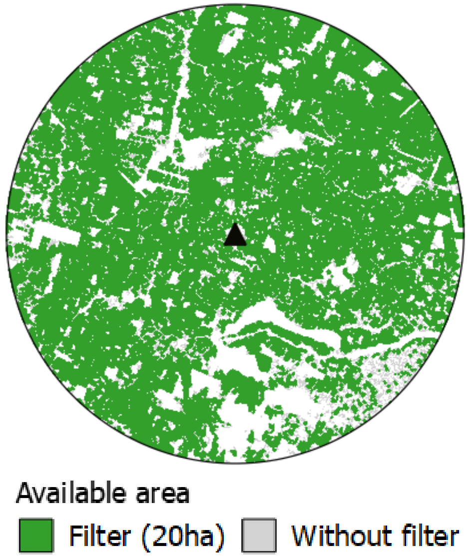
The risks of extensive monoculture (1)

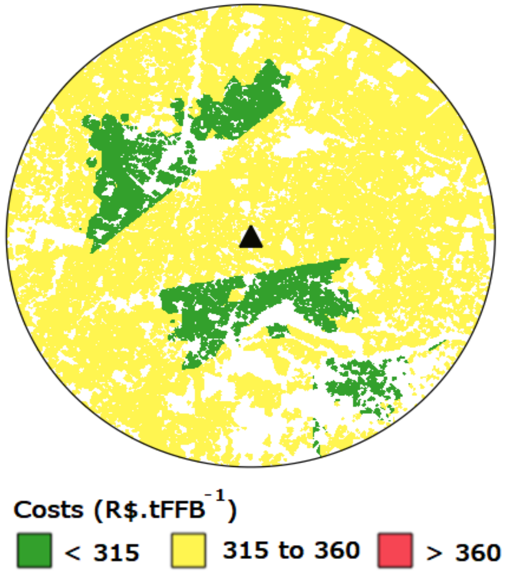




- The high potential in some sites could bring the risk of extensive monoculture, as it could be the case of producing around Terra Nova do Norte (MT) and Xinguara (PA) (individually, the two sites with the largest potentials). In the next slide some comments are also presented to the São Miguel do Guamá (PA) case.
- In addition to the risk of monoculture, a second issue is related to compliance with the National Forest Code: in the Amazon biome, in the case of deforestation after 2008 (not the case of the areas assessed in this report), and depending on the size of the property, it is necessary to maintain untouched vegetation in 80% of the total area (see Supplementary Material). Anyway, to minimize criticism, Agropalma (2017), which has all its production in Pará certified by RSPO, says that it maintains an area equivalent to 164% of its production area covered by natural vegetation.
- The upper figure shows the areas with potential for palm production around Terra Nova do Norte. After the aggregation procedure (filtering to at least 20 hectares), the estimated area for production (green dots) represents 47% 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 supply required for the production of 300.1 t.day^{-1} of SAF, it would be necessary to have palm production in 26% of the areas in a circle of 50 km radius around Terra Nova do Norte (more than 204 thousand hectares).

The risks of extensive monoculture (2)





- The upper figure shows the areas with potential for palm production around Xinguara (PA). After the adopted aggregation procedure (filtering to 20 hectares), the estimated area for total production (green dots) represents 75.2% of the area inside the circle.
- The lower figure shows the areas classified according to the estimated annual cost of fresh fruit production. Considering the required supply (exclusively from one site) in order to make possible the production of 300.1 t.day^{-1} of SAF, it would be necessary to have palm production in 28.7% of the areas in a circle of 50 km radius around Xinguara (more than 225 thousand hectares; being not all them with lower producing costs).
- As for São Miguel do Guamá (PA), the results are 26% and 13.7%, respectively, for the total palm production and for the palm production that would make possible the production of 300.1 t.day^{-1} of SAF.
- Among the three cases reported, in São Miguel do Guamá it would be less difficult to minimize the risk of monoculture. Again, it is concluded that it would be necessary to diversify the supply, but it must also be remembered that there are a set of boundary conditions that impose restrictions (e.g. costs, required infrastructure, etc.).

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 palm would occur displacing pasturelands, and in areas that were not converted after January 2008.
- Regarding Principle 1, Default Life Cycle Emissions Values for the HEFA route based on palm are available only for Malaysia and Indonesia (76.5 $gCO_2eq.MJ^{-1}$, being more than half due to ILUC effects). In this sense, the potential SAF producer in Brazil would have to assess the carbon footprint of its own production, using the methodology approved. As the carbon footprint of the fossil jet fuel is 89 $gCO_2eq.MJ^{-1}$, avoided GHG emissions on life cycle basis in the case of the two Asian countries would be only 14.0% (the minimum required is 10%). In the Brazilian case, besides the concerns related to ILUC effects, the impact of palm oil transportation over long distances is a matter of concern.

Other sustainability aspects (1)

- The palm Agroecological Zoning, here used as reference, considers only deforested areas prior to 2008. To be conservative, the areas with suitability according to the Zoning were combined with the restrictions adopted in this project, which leads to the exclusion of those areas covered by natural vegetation in January 2008, in addition to areas defined as indigenous reserves and afro-descendant settlements, for example. Moreover, only areas used for pasture in 2018 were considered in the assessment.
- This procedure results in a safe assessment of areas for palm production in sensitive biomes, such as the Amazon and Cerrado, but does not mitigate concerns about direct and induced deforestation.
- For example, it has been observed that between 13%-90% of the recent oil palm expansion has caused deforestation in several tropical countries (Benami et al., 2018). Given the historical links between deforestation and the development of oil palm, in addition to the growing deforestation in Brazil, a SAF project based on the production of palm oil in the Amazon would obviously draw much attention. Benami et al. (2018) question whether Brazil would succeed in decoupling palm oil growth from deforestation, which it managed to do relatively well in Pará between 2010 and 2014.

Other sustainability aspects (2)

- One issue that may be a weak aspect of SAF production based on palm oil is the history of reported violations of land and water use rights in Pará, Mato Grosso and Bahia. As shown earlier, many areas with good potential for palm production coincide with regions where there are many reported violations, including those associated with violent episodes (for example, murders).
- In the case of Terra Nova do Norte (MT), the bulk of reported violations are related to litigation in settlement areas in neighboring municipalities (e.g. Peixoto Azevedo and Nova Guarita) (CPT, 2019).
- In two of the three cases considered in Pará state (São Miguel do Guamá and Xinguara) there are several reported cases of violations of land use rights in neighboring municipalities, being these cases associated with settlement disputes, illegal logging, illegal panning and mining. From the information available, it seems that no record is related with palm production (CPT, 2019).
- In Bahia, there are no records of violations to water use rights exactly at the two production sites here considered, but rather documented violations in nearby areas in association with restricted access to water, destruction of assets, including historic heritage, and pollution (CPT, 2019).

Conclusions

- The reported case study shows that the production of SAF based solely on palm oil would barely be feasible in Brazil, even in the medium to long term. As it is unreasonable to expect significant growth in palm oil yield, feasibility would depend on a set of smaller contributions related, for example, to gains in scale and reduced transportation costs.
- In practice, a constraint is that the best potential for palm production is in contentious regions from a socioeconomic and environmental points of view, and distant from where the industrial infrastructure is located.
- In addition, it seems a challenge to have SAF production recognized as sustainable, first because of the potentially low contribution to avoiding GHG emissions. Likewise, the investor would have to pay special attention to aspects associated with deforestation, actions that ensure the preservation of native vegetation, non-involvement with conflicts related to the violation of land and water use rights, etc.
- In summary, it would be necessary to conceive a innovative project in the Brazilian context, exploring transport modals like railways or even boats, and/or the location of the industrial SAF plant closer to where the feedstock would be available.
- It would be convenient to consider the combination of feedstock, indeed as an alternative to reduce risks. In this sense, in another case study palm oil will be considered a complementary feedstock to the production of SAF based on the HEFA-SPK pathway.

References (1)

- Agrianual. 2020. Agrianual database (information not publicaly available). IEG FNP Agribunisses. Available at http://www.agrianual.com.br/
- Agropalma. 2017. Relatório de Sustentabilidade 2017. Available at www.agropalma.com.br.
- Almeida, JR. 2012. Criação de Valor Sustentável e o Óleo de Palm no Brasil. FGV/EAESP.
- Andrade, EB. 2015. A cadeia produtiva da palma de óleo no Estado do Pará: Uma avaliação crítica. Brasília.
- Anwar, R, Sitorus, SRP, Fauzi, AM, Widiatmaka, Machfud, 2014. Technical Culture and Productivity of Oil Palm in Several Plantations in East Kalimantan. International Journal of Latest Research in Science and Technology, 3(2), 19-24.
- Benami, E, Curran, LM, Cochrane, M, Venturieri, A, Franco, R, Kneipp, J, Swartos, A. 2018. Oil palm land conversion in Pará, Brazil, from 2006–2014: evaluating the 2010 Brazilian Sustainable Palm Oil Production Program. Environmental Research Letters, 13.
- CPT – Comissão Pastoral da Terra. 2019. Database to be accessed through https://www.cptnacional.org.br/
- Dias-Filho, MB. 2005. Degradação de Pastagens: Processos, causas e estratégias. Embrapa Amazônia Oriental: Belém, Brazil, 2005; pp. 1–173, ISBN 978-85-911831-0-4.
- Dias Filho, MB. 2014. Diagnóstico das Pastagens no Brasil. Embrapa Amazônia Oriental: Belém, Brazil; p. 22.
- Dorsa Engenharia. Óleo de Palma: Processo de extração. Relatório Técnico. Available at https://docplayer.com.br/48137705-Oleo-de-palma-o-processo-de-extracao.html.
- EMBRAPA. 2006. Viabilidade Técnica e Econômica de Produção de Ésteres de Óleo de Palma, para Utilização como Substituto de Óleo Diesel, na Amazônia.
- EMBRAPA. 2010. Zoneamento Agroecológico, Produção e Manejo para a Cultura da Palma de Óleo na Amazônia. Rio de Janeiro.
- EMBRAPA. 2019. Available at https://www.embrapa.br/en/codigo-florestal/area-de-reserva-legal-arl

References (2)

- EMBRAPA. 2020. Available at https://www.cerradoeditora.com.br/cerrado/tecnologias-embrapa-agroenergia-expoe-tecnologias-para-agroenergia/
- EU HORIZON Work Programme 2016-2017. 2019. General Annex. Available at: ec.europa.eu/research/participants/data/ref/h2020/other/wp/2016-2017/annexes/h2020-wp1617-annex-ga_en.pdf.
- Forkenbrock, DJ. 1998. External Costs of Truck and Rail Freight Transportation. Public Policy Center, The University of Iowa. Available at https://ir.uiowa.edu/cgi/viewcontent.cgi?article=1001&context=ppc_transportation
- Freitas, FLM, Sparovek, G, Berndes, G, Persson, UM, Englund, O, Barretto, A., Mörtberg, U. 2018. Potential increase of legal deforestation in Brazilian Amazon after Forest Act revision. Nature Sustainability, 1, 665-670.
- IBGE – Instituto Brasileiro de Geografia e Estatística. 2020. Information available at https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9105-producao-da-extracao-vegetal-e-da-silvicultura.html?=&t=resultados
- ICAO – International Civil Aviation Organization. 2019. ICAO document series. Available at CORSIA https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-Eligible-Fuels.aspx
- Jalani, BS, Basiron, Y, Darus, A, Chan, KW, Rajanaidu, N. 2002. Prospects of Elevating National Oil Palm Productivity: a Malaysian Perspective. Oil Palm Industry Economic Journal, 2(2).
- Klein, BC, Chagas, MF, Junqueira, TL, Rezende, MCA, Cardoso, T F, Cavalett, O, Bonomi, A. Techno-economic and environmental assessment of renewable jet fuel production in integrated Brazilian sugarcane biorefineries. 2018. Applied Energy, 20, p. 290-305.
- LAPIG - Laboratório de Processamento de Imagens e Geoprocessamento. 2018. Atlas das pastagens brasileiras. Available at pastagem.org/atlas/map.
- Le Freuve, P. 2019. Are biofuels ready for take off? International Energy Agency. Available at https://www.iea.org/commentaries/are-aviation-biofuels-ready-for-take-off.
- Leite, CE, Pereira, LRS, Marinho, CJM, Bittencourt, JA, 2016. Análise Comparativa Custos entre os Meios de Transporte Rodoviário e Ferroviário. XII Congresso Nacional de Excelência em Gestão.
- Lemos, R. 2020. Custos do Transporte Ferroviário. Instituto Brasil Logístico. Available at https://institutobrasillogistico.com.br/custos-do-transporte-ferroviario/
- MAPA – Ministério da Agricultura, Pecuária e Abastecimento. 2011. Information available at https://www.gov.br/agricultura/pt-br/assuntos/riscos-seguro/programa-nacional-de-zoneamento-agricola-de-risco-climatico/portarias/safra-vigente/bahia

References (3)

- MAPA – Ministério da Agricultura, Pecuária e Abastecimento. 2018. Diagnóstico da produção sustentável da palma de óleo. Available et https://aprobio.com.br/novosite/wp-content/uploads/2018/08/Diagn%C3%B3stico-Prod-Sust-da-Palma-de-%C3%93leo_MAPA_2018.pdf
- MAPBIOMAS. 2020. Project web page available at https://mapbiomas.org/
- Mehta, PS; Anand, K. 2009. Estimation of a Lower Heating Value of Vegetable Oil and Biodiesel Fuel. Energy & Fuels, 23, 3893–3898.
- Paterson, RRM, Kumar, L, Shabani, F, Lima, N. 2017. World climate suitability projections to 2050 and 2100 for growing oil palm. Journal of Agricultural Science, 155, 689–702.
- Pereira, OJR, Ferreira, LG, Pinto, F, Baumgarten, L. 2018. Assessing Pasture Degradation in the Brazilian Cerrado Based on the Analysis of MODIS NDVI Time-Series. Remote Sens. 2018, 10, 1761.
- Platts Global Index. 2020. Available through IATA Jet Fuel Price Monitor Information https://www.airportwatch.org.uk/iata-jet-fuel-price-monitor-information/
- Prussi, M, O'Connell, A., Lonza, L. 2019. Analysis of current aviation biofuel technical production potential in EU28. Biomass and Bioenergy, 130.
- Reis, HFAF, Lima, LP, Perez, R. 2017. Palma no Brasil – viabilidade da produção de óleo ou biodiesel? Revista de Política Agrícola, XXVI (2), 20-30.
- Semedo, I. 2002. Viabilidade econômica do dendê: um estudo de caso da substituição das plantações nativas por dendezeiros geneticamente melhorados. Monografia (Graduação em Ciências Econômicas): Universidade Feral da Bahia, Salvador.
- Silva, JSO. 2006. Produtividade de óleo de palma na cultura do dendê na Amazônia Oriental: influência do clima e do material genético. Dissertação: Universidade Federal de Viçosa.
- Silva, MS et al. 2016. Cadeia de Produção Agroindustrial do Biodiesel na Bahia: Caracterização e diagnóstico do elo agropecuário. Educação, Tecnologia e Cultura - E.T.C., 14. Available at: <http://www.publicacoes.ifba.edu.br/index.php/etc/article/view/46>.
- Teixeira, LC. Potencialidades de oleaginosas para produção de biodiesel. Informe Agropecuário, v.26, p.18-27, 2005.
- USDA – United States Department of Agriculture. 2020. Oil Seeds: World Market and Trade. Available at https://www.fas.usda.gov/data/oilseeds-world-markets-and-trade.
- Wang, W-C, Tao, L, Markham, J, Zhang, Y, Tan, E, Batan, L, Warner, E, Biddy, M. 2016. Review of biojet fuel conversion technologies (Technical Report No. NREL/TP-5100-66291). National Renewable Energy Laboratory, Golden, CO, USA.

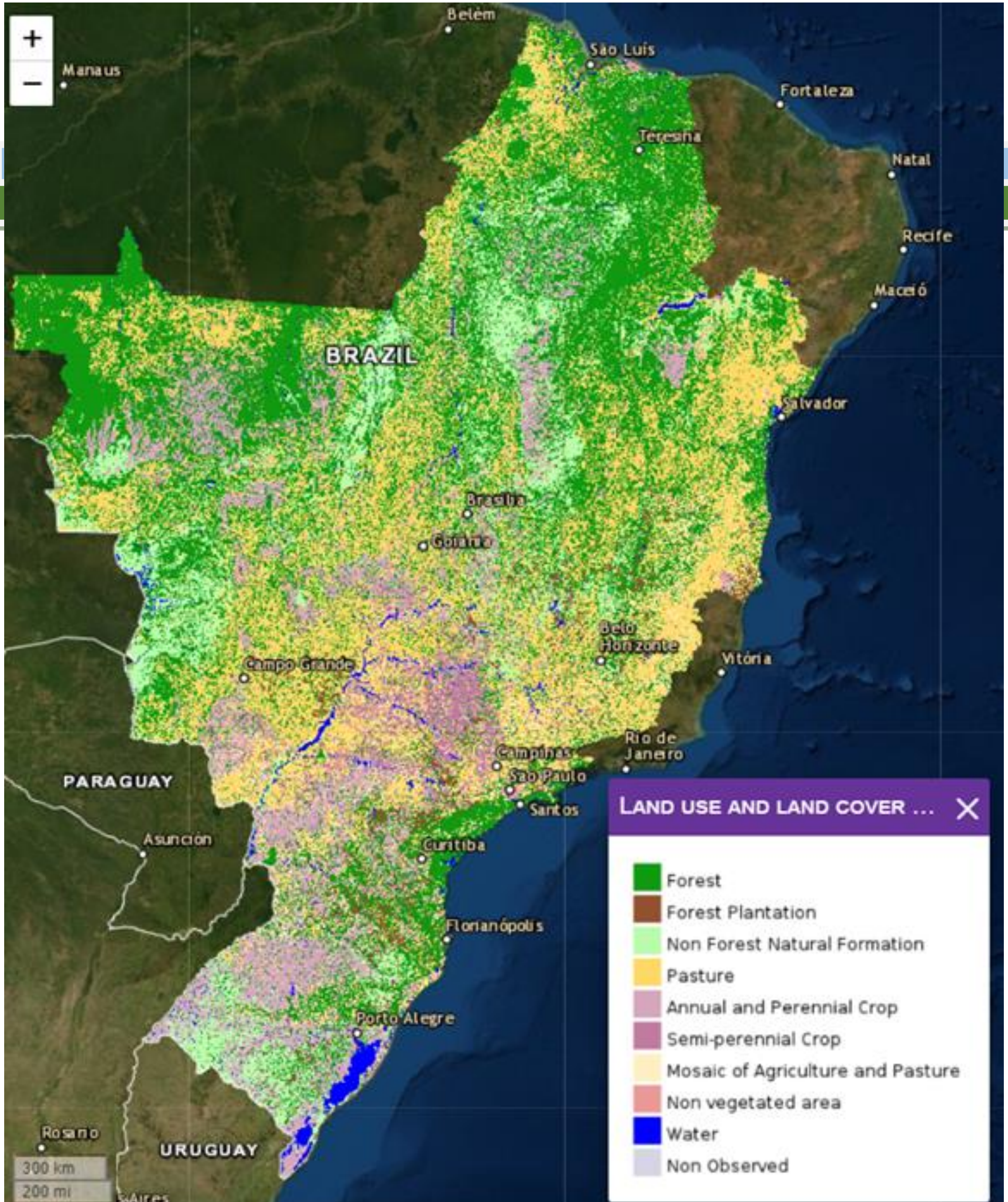
Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

Case study: HEFA pathway / palm oil

Supplementary Material

List of Contents

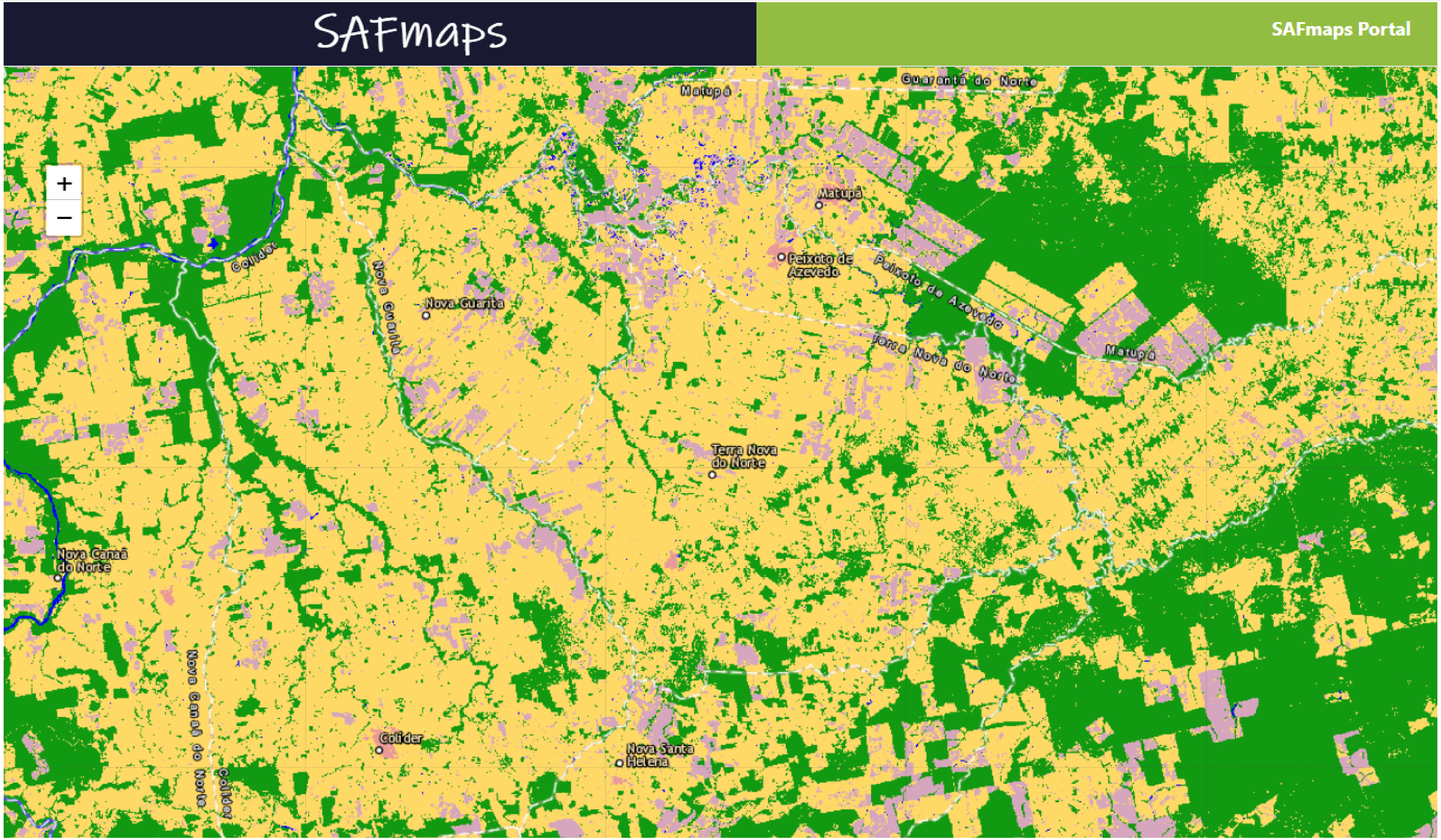
- Land use and land cover;
- Sensitive areas;
- Reported violations to land use and water use rights;
- Rail transport;
- About degraded pasturelands;
- Jet fuel prices;
- About CORSIA and eligible fuels;
- About the Forest Code;
- Agricultural costs;
- Palm processing costs;
- Industrial costs.



Land use and land cover in 2018

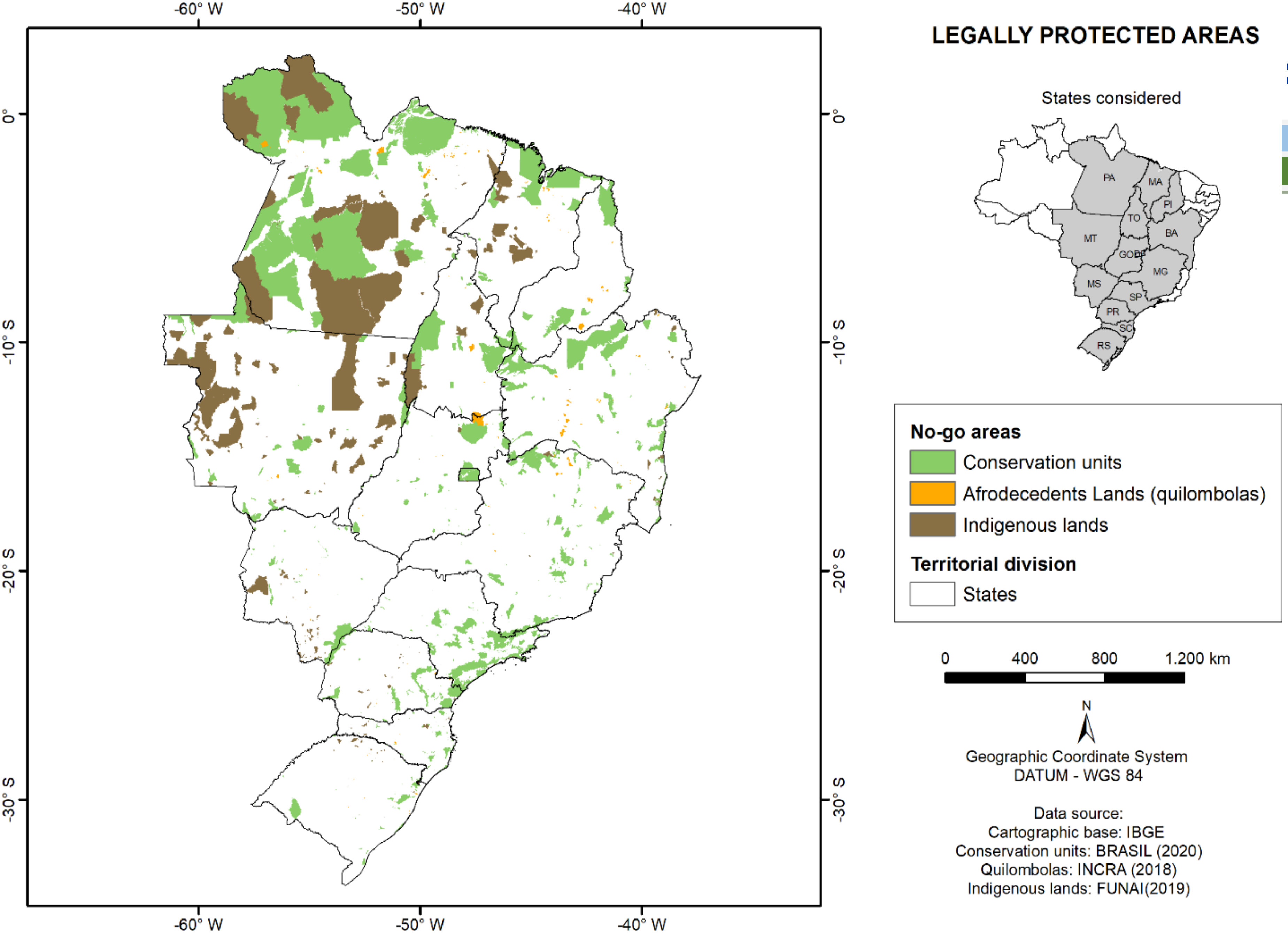
- Information of land use and land cover available at the platform database corresponds to 2018. The source is Mapbiomas.
- Figure shows the land use & land cover map available at the database and used in this study. The figure available at the database does not present details for state of Pará, but all images from the Mapbiomas project can be accessed through “Useful links”.
- The next slide shows a partial zoom-in image for north of Mato Grosso.

Land use and land cover in 2018 – detailed image for north of Mato Grosso

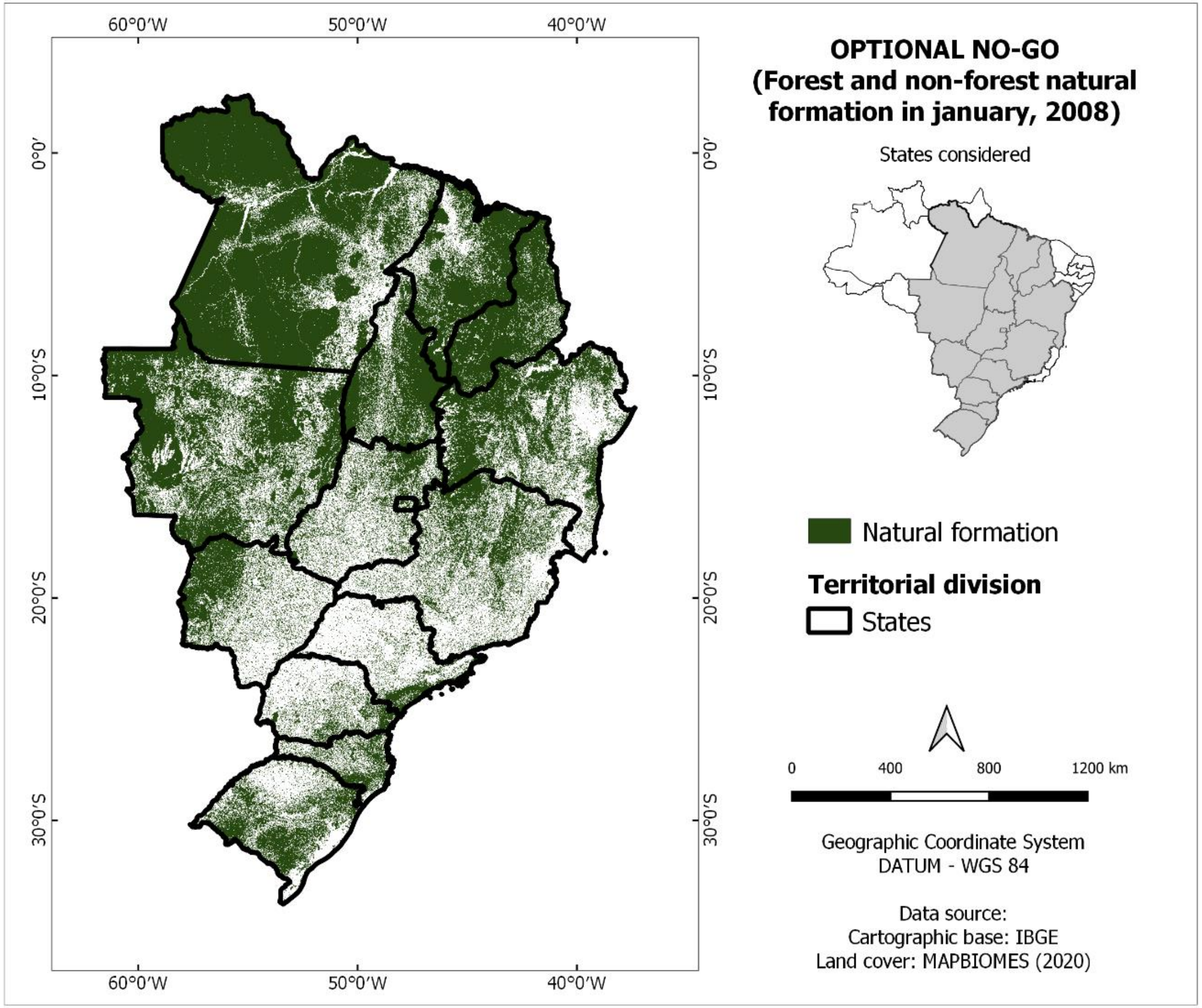


- Figure shows the land use & land cover map for north of Mato Grosso, highlighting the region of (and around) Terra Nova do Norte.

Sensitive areas (1)

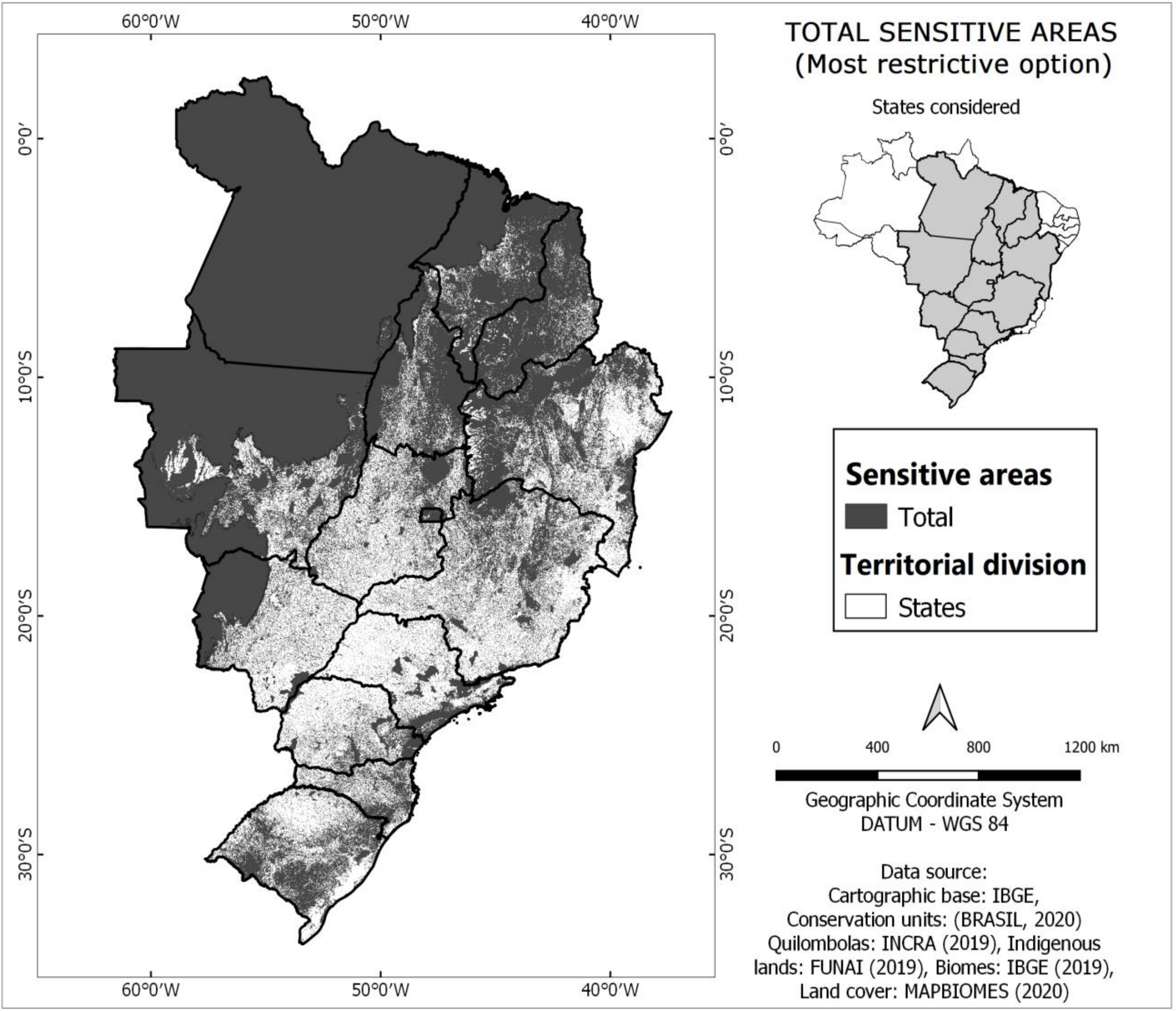


- Feedstock production cannot occur in legally protected areas.
- Legally protected areas include conservation units (for environmental reasons), the land that belongs to Afro-descendants (i.e. quilombola areas, or Afro-Brazilian settlements) and reserves of indigenous peoples.



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.

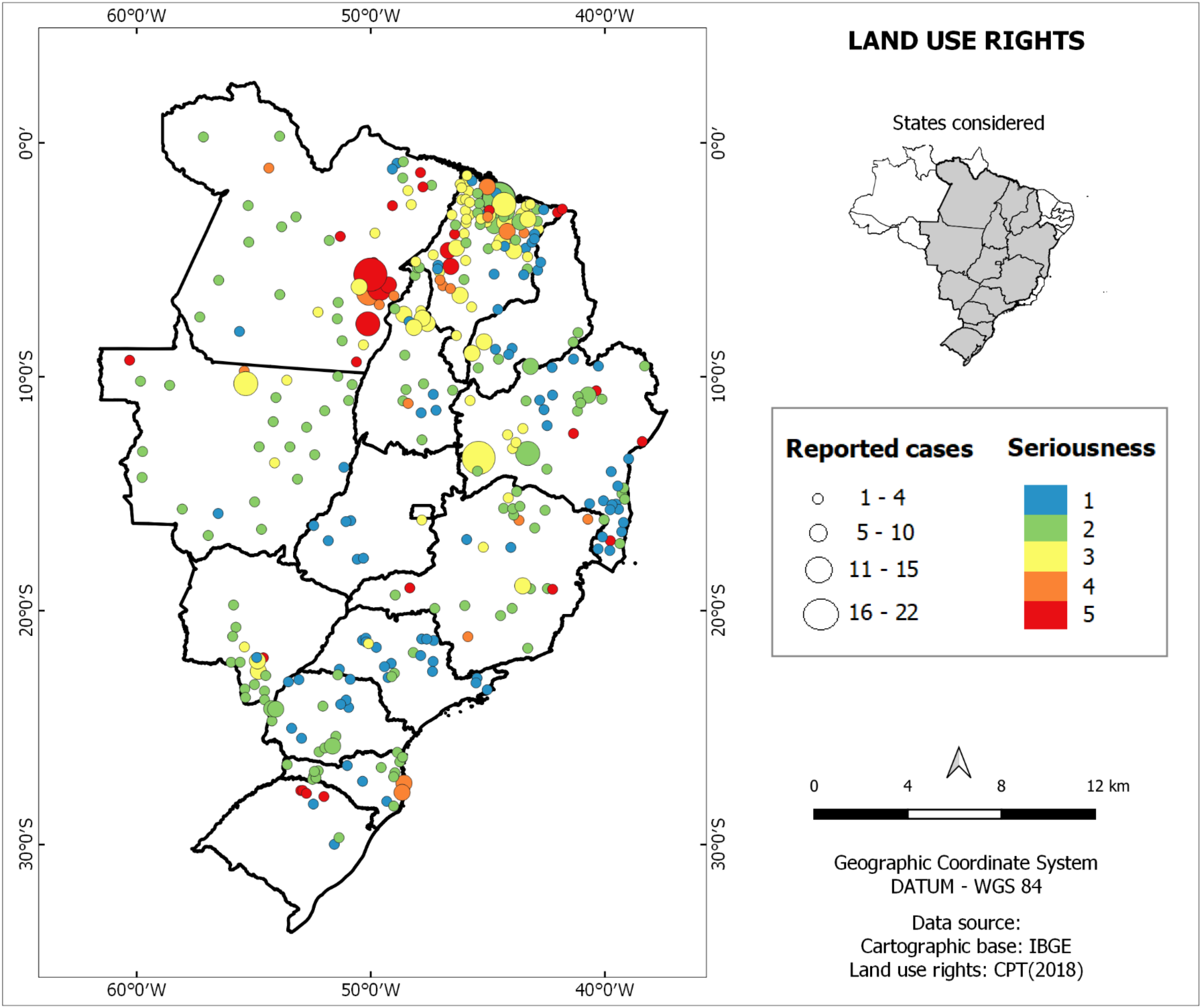


Sensitive areas (3)

SAFmaps

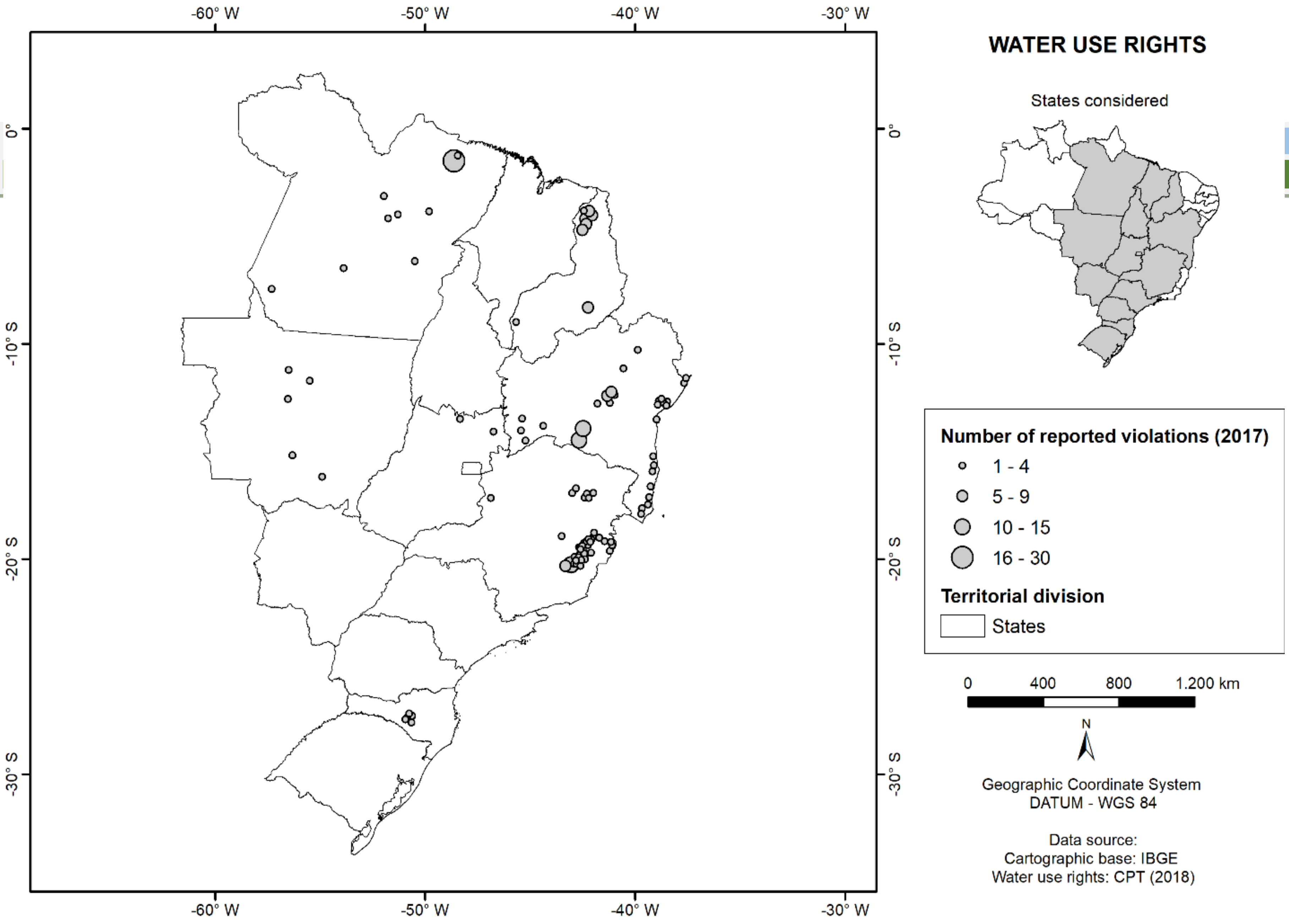
- The figure combines the previous map with areas of the biomes Amazon Forest and Pantanal, which are biodiversity hot-spots.
- In this project, this is the most restrictive option.
- Both maps include, as unusable areas for feedstock production, the lands classified as national parks, areas protected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

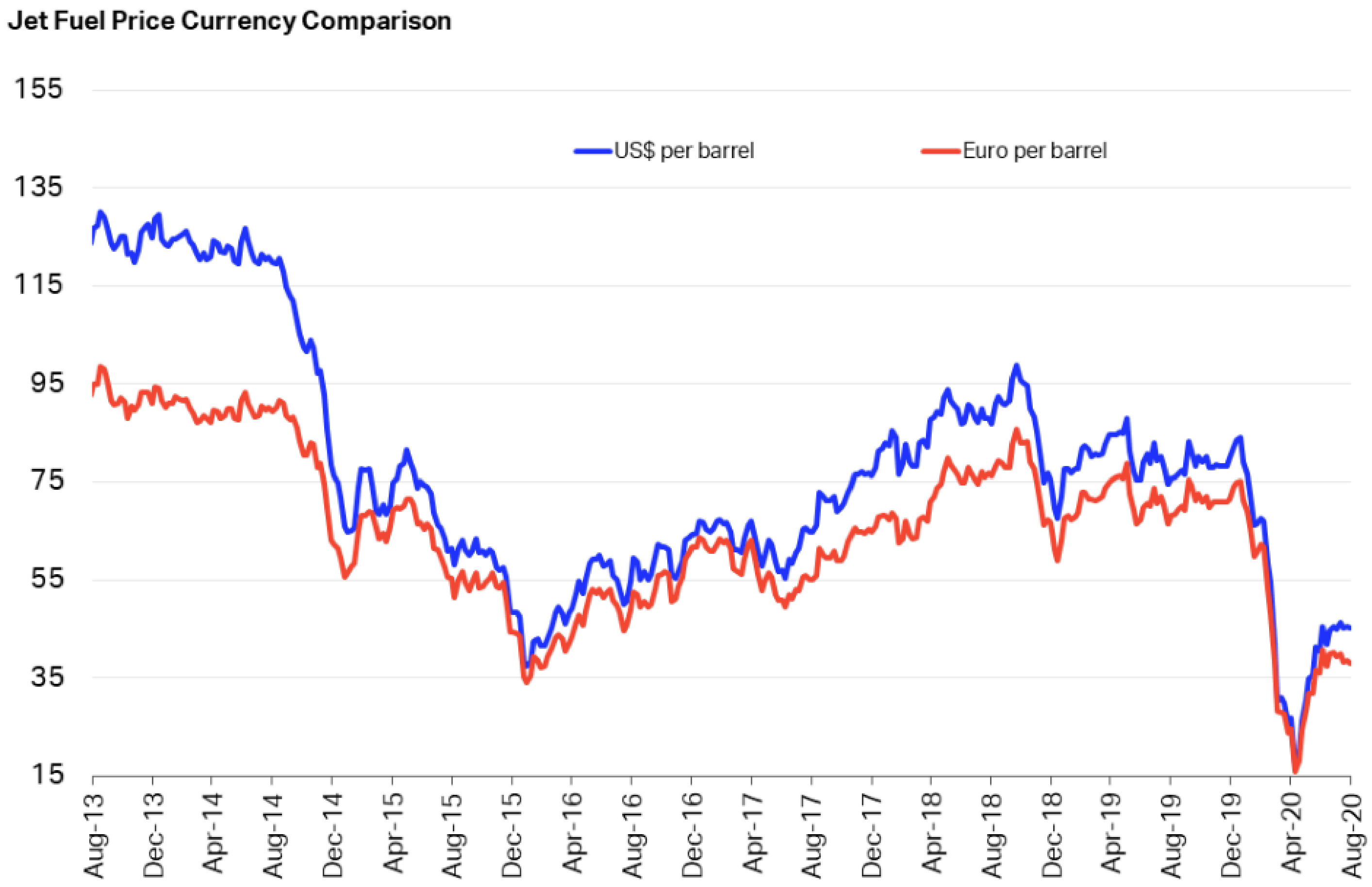
Rail transport

- In order to estimate the cost of transporting palm oil by rail instead of by truck, a literature review was carried out. Freight costs vary with several factors, especially with the distance and the number of transfers. The same estimated road distance between the palm oil extraction site and the SAF industrial production unit (three oil refineries) was assumed for the railway distance. No transfers were assumed between origin and destination.
- From the literature review (Forkenbrock, 1998; Leite et al. 2016; Lemos, 2020), it was observed that the cost ratio of rail/road freight, expressed in $\$.t^{-1}.km^{-1}$, varies between 0.31 and 0.74 for distances greater than 1,000 km, with a clearer indication that 0.50 could be used for a preliminary assessment.
- Thus, in the exercise carried out in association with the HEFA-SPK route for palm oil, it was assumed that the freight cost for rail transport would be 50% of the estimated freight cost for transport by truck, assuming the same distances between origin and destination.

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).

Jet fuel prices: historical data and worldwide variations



Source: Platts, Datastream

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

- Figure shows the evolution of jet fuel prices (global average) from August 2013 to August 2020.
- 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.

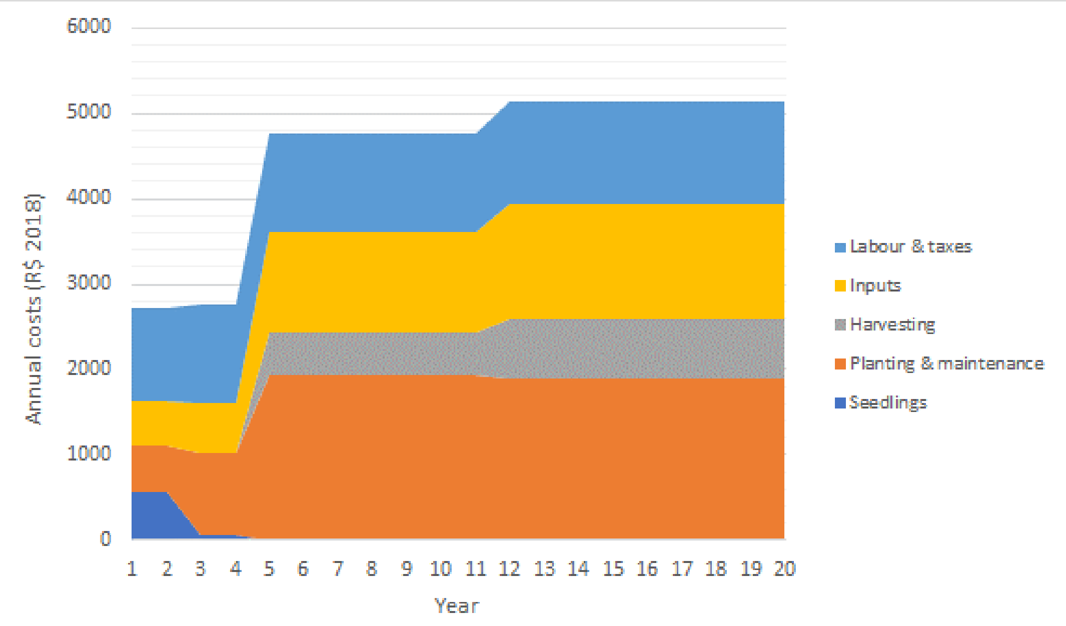
Theme	Principle	Criteria
1. Greenhouse Gases (GHG)	Principle: CORSIA eligible fuel should generate lower carbon emissions on a life cycle basis.	Criterion 1: CORSIA eligible fuel shall achieve net greenhouse gas emissions reductions of at least 10% compared to the baseline life cycle emissions values 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.

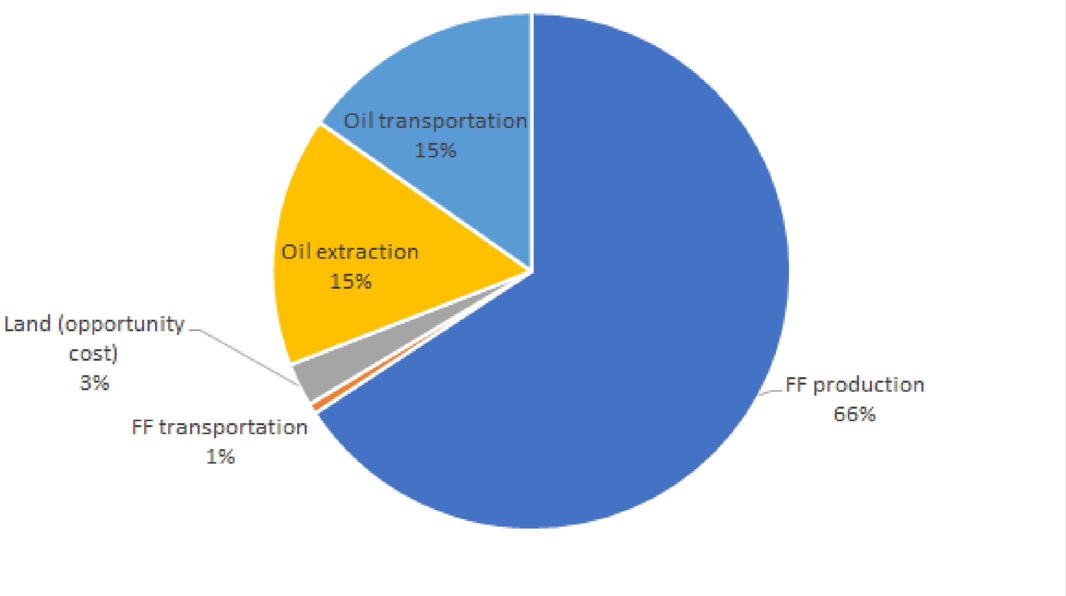
Source: CORSIA (2019)

Forest Code

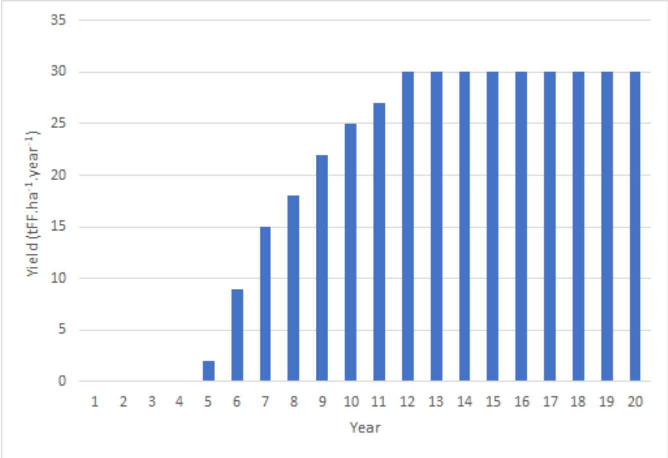
- According to Law 12.651, of 2012 (known as the new version of the Forest code), every rural property must maintain an area covered by native vegetation, as a Legal Reserve. This area, ideally inside the property, has the function of: 1) assisting the conservation and rehabilitation of ecological processes, 2) promoting the conservation of biodiversity, and 3) to shelter and to protect wild fauna and native flora (EMBRAPA, 2019).
- For rural areas in the Amazon biome, the area to be maintained is equal to 80% of the total area of the property, but there are conditions and exceptions. In the Cerrado biome the area to be preserved is equal to 35% of the total area.
- For instance, if deforestation occurred between 1989 and 1996, obeying the minimum of 50% of the Legal Reserve in force at the time, there is no need to reach 80%. In addition, for small rural properties that had remnants of native vegetation in 2008, in total lower than that provided for in the new Forest Code, the Legal Reserve will be the area occupied with native vegetation existing in that year. Moreover, under certain conditions the area of Legal Reserve may be limited to 50% of the total property.
- Despite all the exceptions provided for in the law, it is clear that some area of native vegetation (not tiny in comparison to the planted area) must be preserved, even more so in rural properties in the Amazon, under the risk of multiple questions about the effective sustainability of the project.

Agricultural costs





- Agricultural costs were estimated based on information presented by Agrianual (2020), assuming four years with no production, and a growing yield from year five to 12; from the 12th year until the 20th, the yield would be stable (see the small figure, in the bottom).
- The upper figure shows the expenses in agricultural stage along the whole cycle, classified in different categories. Considering a discount rate of 8% per year, it was estimated the average levelized cost.
- The second figure in the left side shows the cost structure, adding to the cost of producing fresh fruits (FF) the value that corresponds to transportation of FF to the extraction unit, the extraction cost itself, and the oil transportation cost to an oil refinery (REVAP).



Palm processing costs

- The main reference is Reis et al. (2017); the authors present data for an extraction unit with a processing capacity of 57.3 $tFF.h^{-1}$ throughout the year, operating with an annual capacity factor of 49.7%. For other capacities it was estimated the CAPEX and the OPEX using a scaling factor of 0.6
- Andrade (2015) reports ten processing units with a capacity ranging from 12 to 40 $tFF.h^{-1}$. Almeida (2012) mentions that the largest processing unit in Brazil almost capable of entering into operation at that time had a processing capacity of 100 $tFF.h^{-1}$. On the other hand, Engpalm (see video at https://www.youtube.com/watch?v=zBZyb3ul7R0) claims that it designed and built a unit with a capacity of 120 $tFF.h^{-1}$. Here, the range of processing capacities considered ranges from 20 to 120 $tFF.h^{-1}$.
- Following the reference, the cost of extracting palm oil was estimated; revenue from the sale of PKO and bran was considered in the cost estimate.
- The process of oil extraction is described by Dorsa Engenharia.
- The two photos show images of a processing unit in Indonesia. The top photo shows the first stage, at the entrance, while the bottom one shows the feeding into the sterilization process.

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 SAF 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 300.1 tonnes of bio-jet per day, operating all over the year with a 90% capacity factor.
- Based on the reference, the estimated (adjusted) total cost investment would be 662.1 million € (2018).
- For estimating the MSP in each case, a spreadsheet was developed and the procedure was 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