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

Case study: HEFA pathway / combined supply

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Executive summary

SAFmaps

- The case studies developed within the scope of the project aim to illustrate the use of the information available in the platform database to assess the potential for sustainable aviation fuels (SAF) production in Brazil. It is not possible to draw ultimate conclusions based on the results obtained, but an effort was made to make the studies as comprehensive as possible.
- This report is related to the HEFA-SPK route, based on the combined supply of tallow and three vegetable oils (soy, palm and macaw palm). Due to restrictions on the supply of beef tallow - the raw material available is used in large extent in the production of biodiesel and its opportunity costs are high - the decision was not to develop a case study exclusively addressing this raw material.
- It was considered that all four raw materials would contribute equally to the production of sustainable aviation fuels (SAF). Alternatives for raw material pricing were considered, but beef tallow would always be paid according to its market prices, and macaw palm oil - once there is no well-established market - would be paid according to its production costs.
- Adding beef tallow to the basket of feedstocks is not strictly economically advantageous. However, the appeal of using beef tallow would be related to the aim of reducing the carbon footprint of SAFs.
- The best results of minimum selling price (MSP) of SAF are 764 $€.t^{-1}$ (17.8 $€.GJ^{-1}$) in case of self-dedicated production of soy and palm oil, and 912 $€.t^{-1}$ (21.3 $€.GJ^{-1}$) in the case in which soy and palm oil would be valued at market prices.

Summary

- The rationale;
- About the pathway;
- Methodology;
- Livestock and tallow availability in Brazil;
- Assumptions (from the previous cases addressed – soy, macaw and palm);
- Results of the case study, analysis & comparisons;
- Conclusions;
- References;
- Supplementary Material.

The rationale

- In the context of the project, three case studies addressed the production of SAFs based on the pathway HEFA-SPK, considering exclusive use of soy, macaw or palm oil as feedstock. Now, the objective is to carry out a case study in which the input for the production of SAF is a combination of beef tallow and the vegetable oils previously mentioned.
- For this, a previous study was carried out on the potential for obtaining bovine tallow. And for the three vegetable oils considered, some supply alternatives were chosen from the previously evaluated and reported cases.
- The rationale is that the combined supply of raw materials could potentially reduce costs and risks. More than for other routes, the viability of SAF produced through the HEFA-SPK route is very sensitive to the costs of raw materials (Lang & Elhaj, 2014). In practice, competition itself could also minimize the risks of rising prices for some feedstock.
- Taking into account the objective of exploring the best solutions from the point of view of economic viability, and also due to the difficulties of transporting tallow over long distances, only one site was considered for the production of SAF: REVAP (in São José dos Campos, which is the main refinery producing fossil jet-fuel, and which is connected by pipelines to Cumbica airport - the main international airport in Brazil).

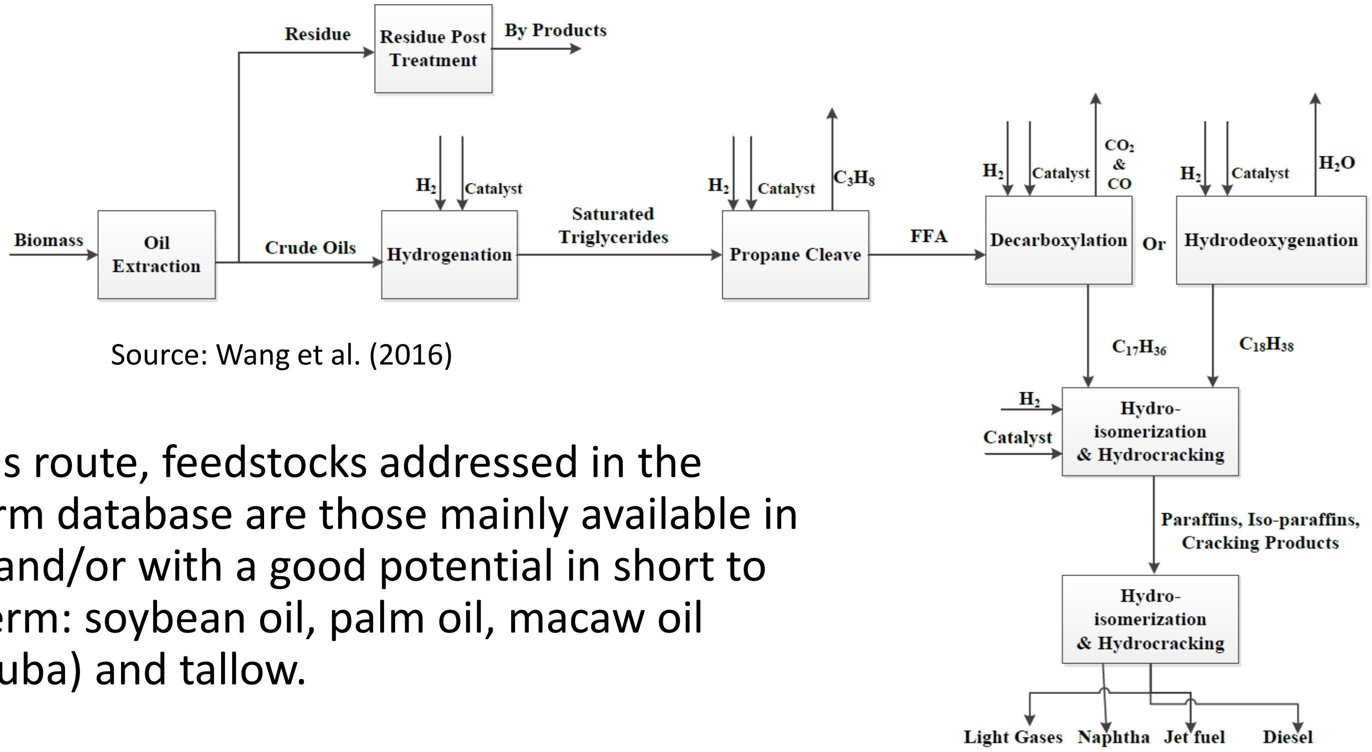
About the pathway (1)

- 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).
- 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).

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)

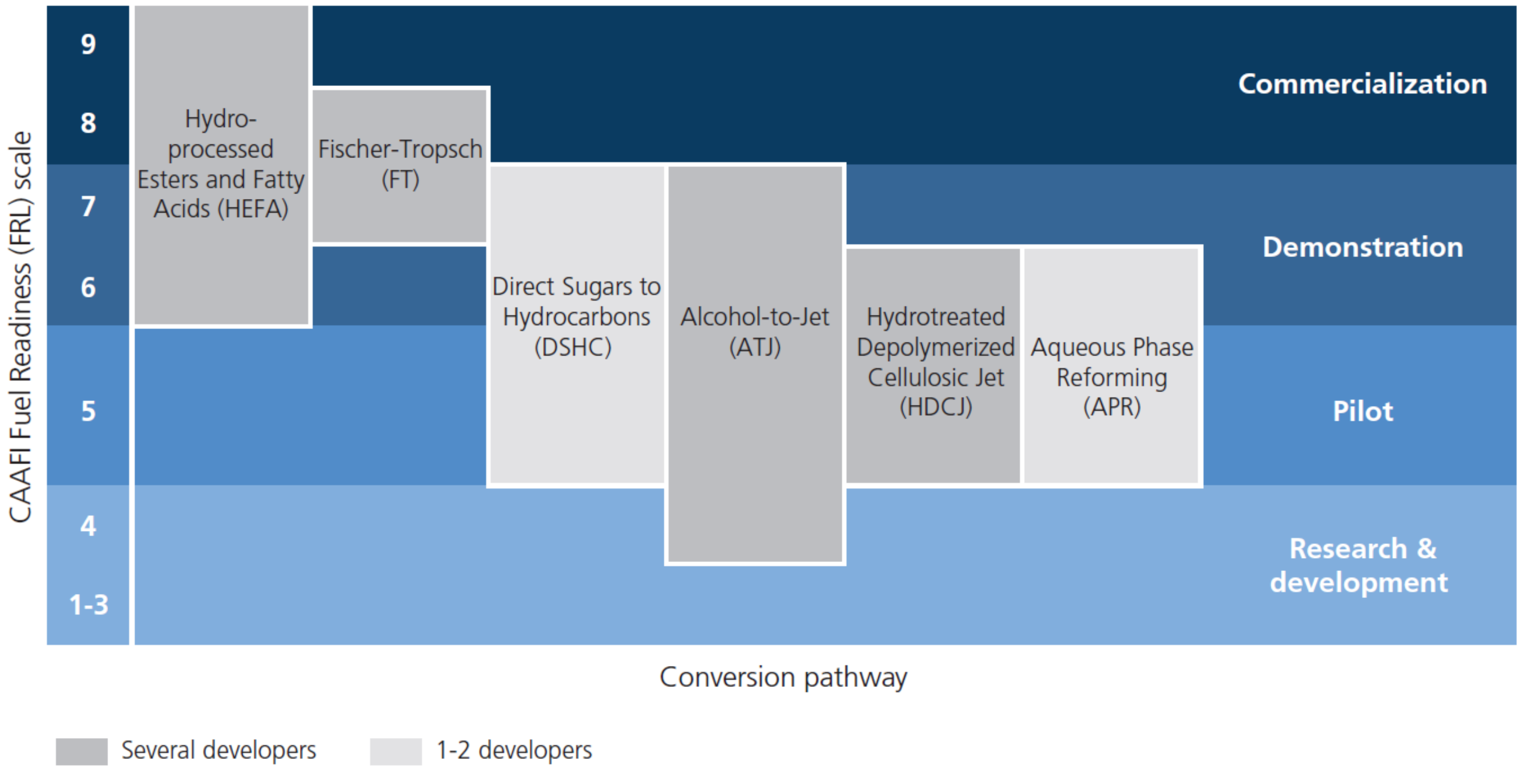


Source: Wang et al. (2016)

- For this route, feedstocks addressed 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.

About the pathway (2)

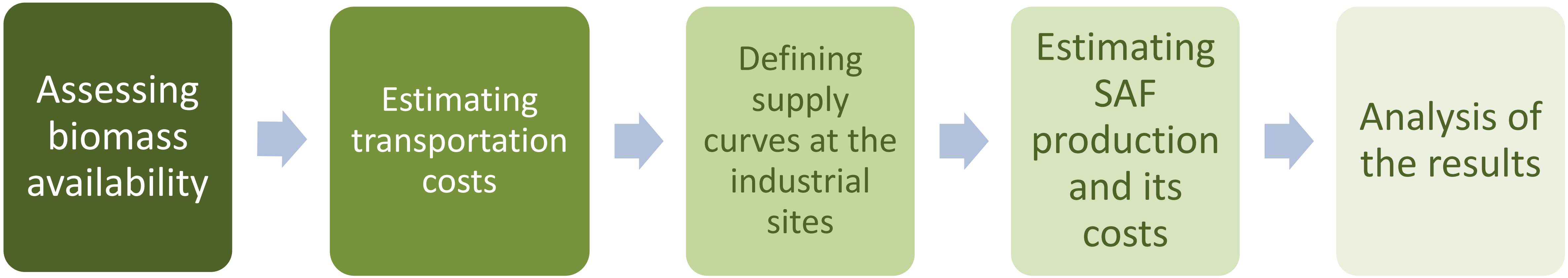
- The figure, extracted from de Jong et al. (2017) is a representation of CAAFI's (Commercial Aviation Alternative Fuels Initiative) Fuel Readiness Level Scale (FRL). It is based on NASA's Technology Readiness Level (TRL) scale and is intended to provide a classification to describe the progress of a 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.

Methodology: general procedure

What is described in this and in the following slides is the methodology used to conduct case studies. In the case of the combined supply of raw materials, adaptations were made to the previously defined methodology.



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

SAFmaps

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 different feedstocks;
- Areas available and where production is desirable;
- Potential yields based on literature review;
- Estimated production costs;
- Transport of biomass 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

SAFmaps

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

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

→

Supply curves 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)

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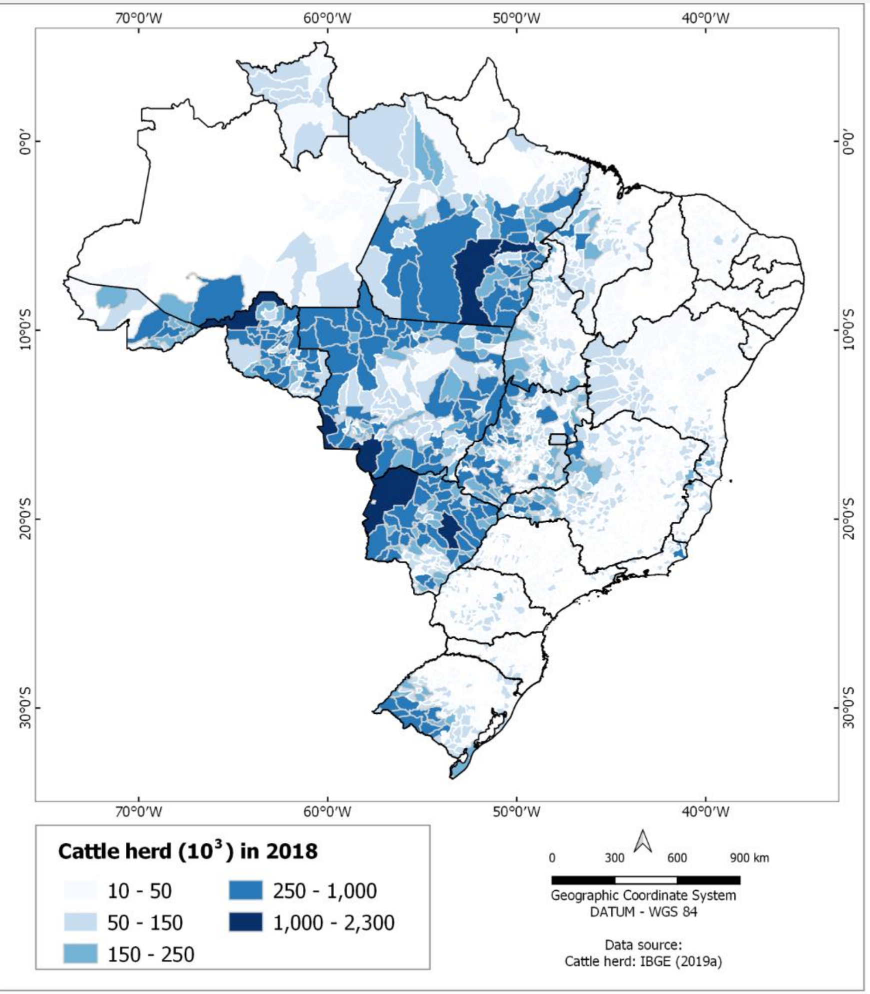
Analysis of the results based on Minimum Selling Prices (MSP), comparing them with those presented in the literature and actual fossil kerosene prices, considering cost reduction opportunities and trends, etc.

Livestock in Brazil and tallow availability (1)



- The figure shows the cattle distribution in Brazil, in 2018. It can be seen that there is large concentration in the central and northern regions.

- Worldwide, Brazil has great importance in the production of animal protein. As for beef, in 2018 Brazil was the second largest producer, behind the USA (19.5% of the total), contributing with 15.8% of the production of 62.8 million tonnes. In the same year, the country was the first largest exporter, contributing 19.9% of international trade, which exceeded 10 million tonnes (Pereira & Vieira Filho, 2019).
- As for pork production, it is highly concentrated in China (47.9% of the total), while Brazil's share was 3.3% in 2018; in the same year, Brazil was the fourth largest exporter, with 8% of the total. And as for chicken meat, Brazil was also the second largest producer in 2018 (14.2% to total), behind the United States (20.2%), but in the same year it was the largest exporter (24.9%) (Pereira & Vieira Filho, 2019).
- In 2018 the slaughter of cattle was estimated at 31.90 million heads. The slaughter of pigs reached 44.20 million heads, while the slaughter of chickens was 5.70 billion heads (IBGE, 2019).

Livestock in Brazil and tallow availability (2)

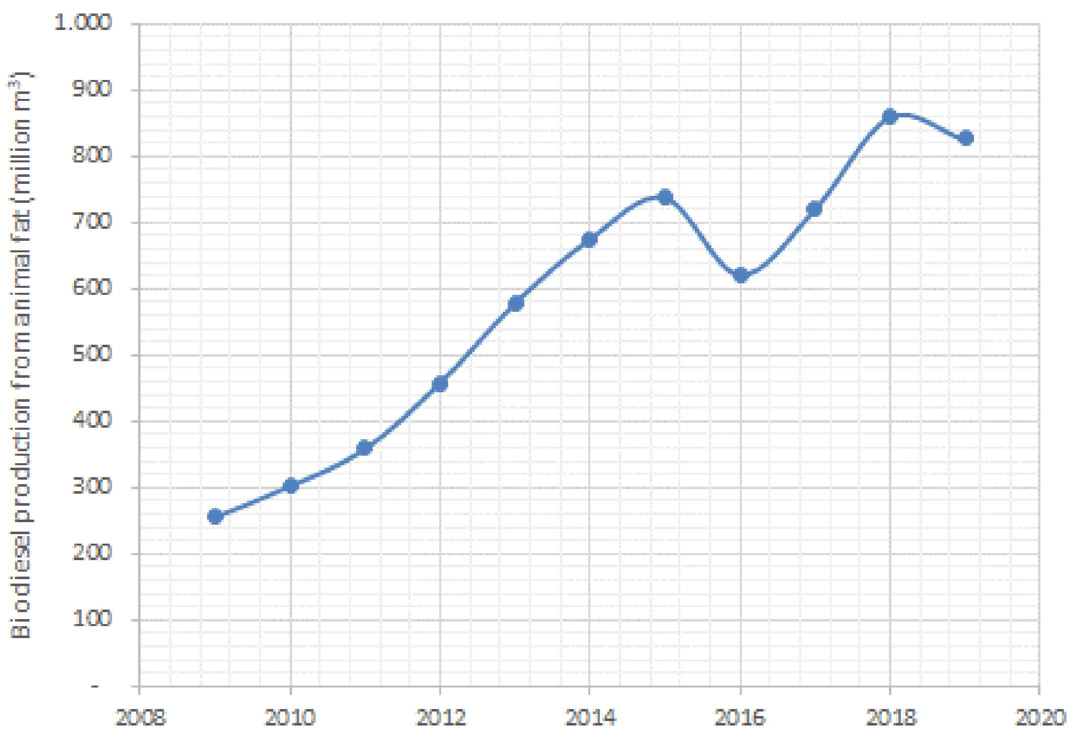
State	Cattle herd (10^6 heads)[1]	Share (%)	Cattle slaughter (10^6 heads)[2]	Share (%)	Cattle slaughter in SIF units (10^6 heads)	Share of the total (%)
MT	30.20	14.1	5.22	16.3	4.84	92.7
MS	20.90	9.8	3.29	10.3	2.93	89.0
GO	22.65	10.6	3.21	10.0	2.63	82.0
MG	21.81	10.2	2.80	8.8	2.15	76.7
SP	10.77	5.0	3.10	9.7	2.49	80.3
PR	9.28	4.3	1.44	4.5	0.90	62.4
RS	12.55	5.9	2.13	6.7	0.89	41.7
Brazil	213.50	100.0	32.0	100	23.10	72.1

Sources: [1] IBGE (2019a), [2] IBGE (2019b)

- The table shows information about cattle herd and slaughters in 2018. Here, the focus was put on the availability of beef tallow and, more specifically, on seven states in the Centre-West, Southeast and South regions. They summed up almost 60% of the herd and 66% of slaughters in that year.

- Brazil had a herd of 213.5 million heads of cattle in 2018. There is animal mobility at some degree and slaughterhouses are closer to the main markets or to the infrastructure for exporting beef.
- An important aspect is that not all slaughterhouses are controlled by the Federal Inspection Service (SIF, for the designation in Portuguese). Here, considering the objective of achieving sustainable SAF production, only beef tallow available in inspected slaughterhouses was considered.

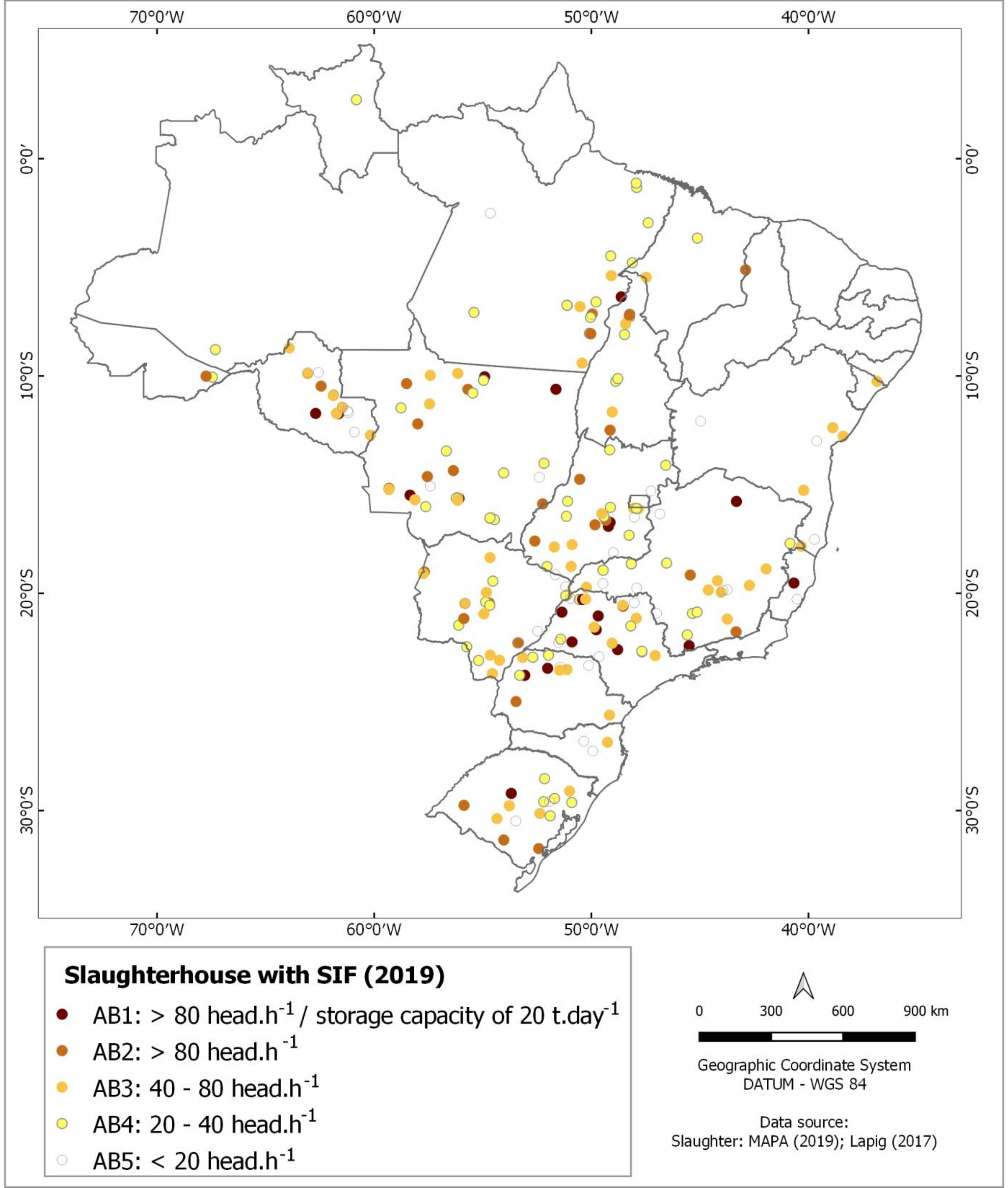
Livestock in Brazil and tallow availability (3)



- It is estimated that 50% of the beef tallow available in 2018 was consumed for the production of biodiesel, or even 70% considering the beef tallow available only in inspected slaughterhouses.

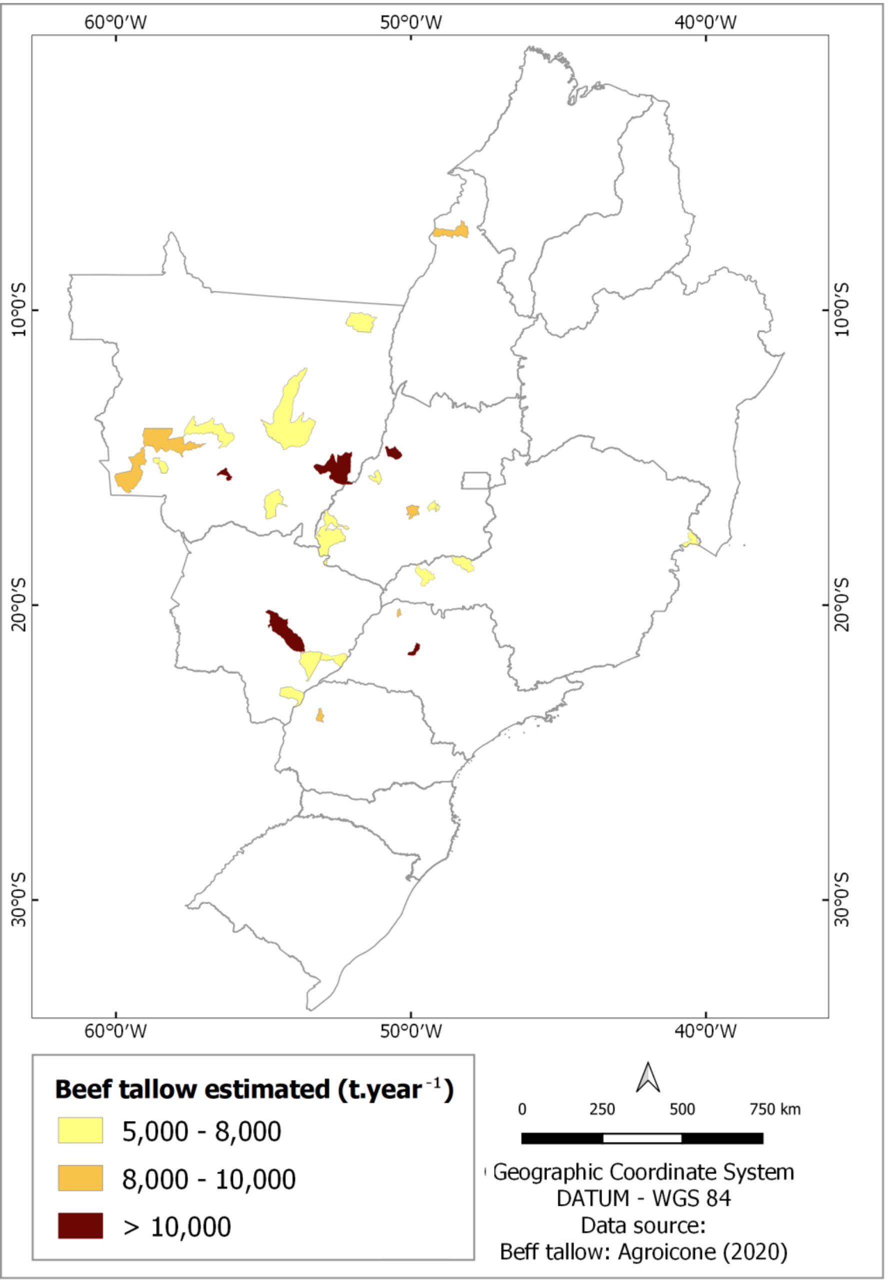
- ABRA (Associação Brasileira de Reciclagem Animal) estimates that the production of animal fat associated with slaughter in 2018 was equivalent to 1.9 million tonnes, being 1.2 million tonnes of beef tallow (plus 474 thousand tonnes from poultry and 133 thousand tonnes from pigs) (ABRA, 2018).
- The main destination for animal fats in recent years has been for the production of biodiesel, which consumed 37.1% of the total raw material available in 2018, followed by the demand of the hygiene and cleaning industry (27.4%) (ABRA, 2018). Other uses include animal feed production, oleochemistry, and use as fuel in boilers (Martins et al., 2011, Levy, 2012). There is also exports of beef tallow for biodiesel production (Editora Stilo, 2019)
- It is estimated that in 2018 animal fats had contributed with 16.2% of biodiesel production in Brazil (i.e. 860.2 thousand m^3), with the largest share (13% of total) (11.5% in 2019) from beef tallow (also in 2019, 2.0% from pork lard and 0.6% from chicken).
- The figure shows the production of biodiesel from animal fats in the period 2009-2019 (ANP, 2020).

Livestock in Brazil and tallow availability (4)



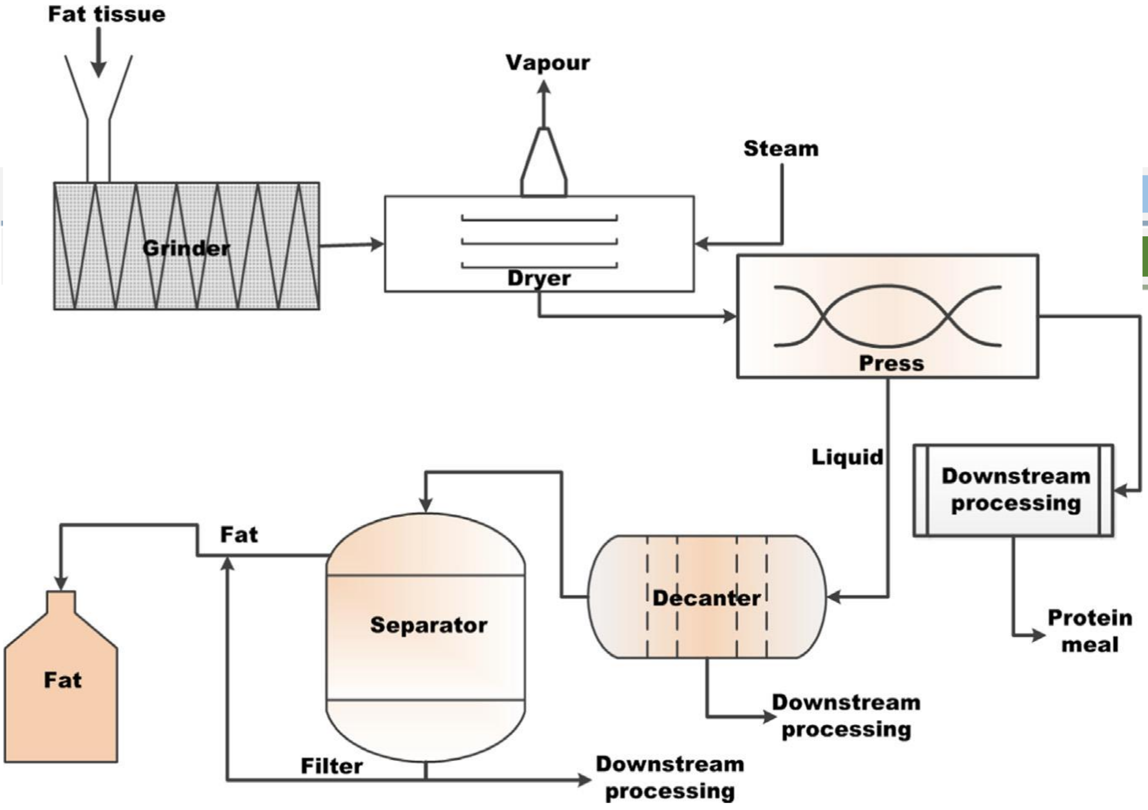
- The map shows the location of cattle slaughterhouses with SIF (2019), classified according to the slaughter capacity (heads/hour). The slaughterhouses are located by LAPIG (2017), based on SIF data.
- The concentration of largest inspected slaughterhouses in seven states is another reason for the focus given in this case study.
- Details of the procedure for selecting the slaughterhouses and for estimating their capacities is presented in the Supplementary Material.

Livestock in Brazil and tallow availability (5)



	Municipality	UF	Beef tallow availability (t.year⁻¹)
1	Várzea Grande	MT	16,458
2	Campo Grande	MS	15,243
3	Promissão	SP	11,341
4	Mozarlândia	GO	10,689
5	Barra do garças	MT	10,011
6	Tangará da Serra	MT	9,684
7	Pontes e Lacerda	MT	9,642
8	Palmeiras de Goiás	GO	9,273
9	Araguaína	TO	8,902
10	Estrela d'Oeste	SP	8,695
11	Cruzeiro do oeste	PR	8,374
12	Bataguassu	MS	7,677
13	Diamantino	MT	6,541
14	Nova Andradina	MS	6,406
15	Araguari	MG	6,372
16	Mineiros	GO	6,214
17	Ituiutaba	MG	6,137
18	Paranatinga	MT	6,058
19	Goiânia	GO	6,039
20	Rondonópolis	MT	5,706
21	Araputanga	MT	5,638
22	Nanuque	MG	5,416
23	Naviraí	MS	5,397
24	Confresa	MT	5,394
25	Santa Fé de Goiás	GO	5,347
26	Senador Canedo	GO	5,273

- In this case study it was assumed that only slaughterhouses with beef tallow availability equal or larger than 5,000 $t.year^{-1}$ would be considered.
- The procedure leaded to the selection of slaughterhouses in 26 municipalities.
- These correspond to 39% of the total tallow available in slaughterhouses with SIF in Brazil, in 2019, or 48% of the tallow available in the 12 states considered in this project.
- The estimated availability would be 207.9 thousand tonnes of tallow per year, or 7.8 $PJ.year^{-1}$ (based on Han et al., 2013a).



Source: Adewale et al. (2015)

- A comprehensive assessment of biodiesel production from animal fats in Brazil was made by Garcilasso (2014).
- The author states that integrated slaughterhouses and rendering plants are common in Brazil. The raw material is transported by trucks to the biodiesel plants.

Rendering and tallow production

- The rendering process converts slaughterhouse animal by-products to a fat and protein meal. Due to its chemical composition, tallow has high melting point and viscosity, causing it to be solid at room temperature. Depending on the process, tallow can be edible or non-edible, being the edible form relatively expensive (Adewale et al., 2015).
- Edible rendering process operates at lower temperatures, and produces edible fats and proteins for use in food products, pet foods, soap, etc. Inedible rendering process operates at higher temperatures, producing inedible tallow and grease for use in animal feed, soap, fatty acids and fuel production. There are two inedible tallow rendering processes: wet and dry processes, being the later cheaper (Han et al. 2013b). The upper figure is a scheme of the dry rendering process.
- Slaughterhouses and rendering plants could be integrated or not. Even with independent rendering plants (collecting fats and greases from various offsite sources), transport distances are reasonably short (Han et al. 2013b).

Assumptions regarding tallow supply

- It was assumed that the same supply chain that exists for the production of biodiesel from beef tallow would be used to supply the raw material, to be mixed with vegetable oils, for the production of SAF.
- As tallow is solid at room temperature, transport requires continuous heating to its final destination.
- It is assumed that tallow is a co-product with a well-established market and that the supply for SAF production will compete with other uses. In this sense, the opportunity cost (i.e. its market price) must be attributed to the raw material.
- Regular quotations of tallow market price is provided by Scot Consultoria (https://www.scotconsultoria.com.br/). By the end of 2018 the price of beef tallow was 2.50 R$.kg^{-1} (15.38 €.GJ^{-1}), tax free, in central Brazil, and 2.65 R$.kg^{-1} (15.38 €.GJ^{-1}, assuming LHV 37.46 MJ.kg^{-1}, according Han et al. (2013b)) in the south of the country.
- In recent years, prices have risen with the increase in the production of biodiesel from tallow, and there is a correlation between the prices of tallow and soybean oil. The price of soy oil is, in principle, the ceiling price of tallow (Martins et al. 2011).
- Market prices vary throughout the year, being generally higher in December-February and lower in July-August (Scot Consultoria, 2020).

Cases studied (1)

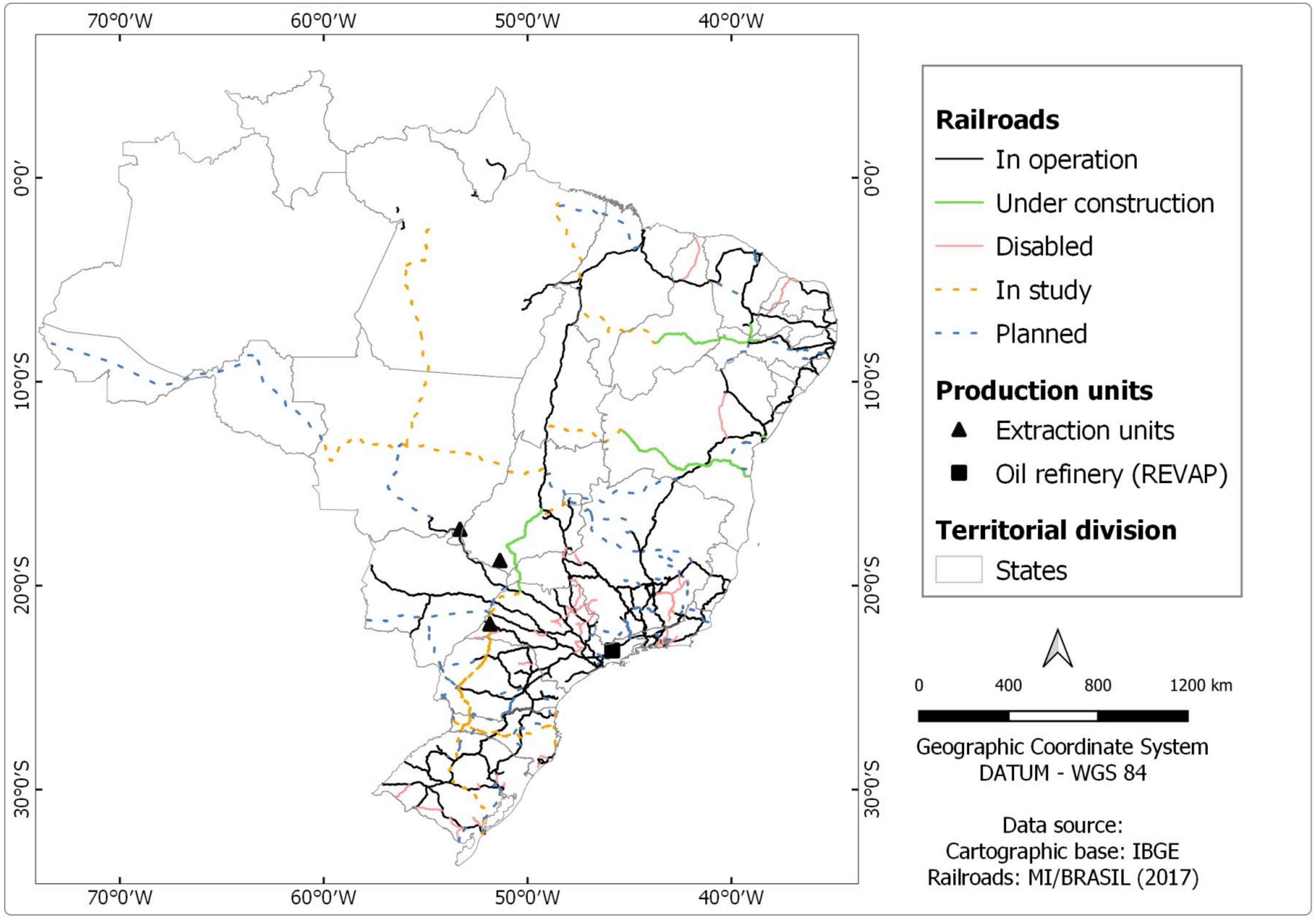
- This case study corresponds to the production of SAF through the route HEFA-SPK, considering combined supply of beef tallow and oil from soy, palm and macauba.
- It was assumed that each feedstock would contribute equally with the required supply.
- The SAF production would be at REVAP, in São José 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).
- As for vegetable oil production, some specific sites, reported in the case studies for soy, palm and macauba, were chosen. It is assumed that it would be possible to deliver by train, at REVAP, the three vegetable oils here considered.
- The two variants ("self-dedicated" and "market price") correspond to the set of price hypotheses for the raw materials considered. In all cases, the FOB price of beef tallow is its opportunity cost in 2018 (i.e. its market prices), while for macaw oil it was considered the cost of production, as there is not yet a well established market. For soy and palm oil, either the market prices in 2018 ("market prices" scenario) or the cost of production from a self-dedicated plantation were considered ("self-dedicated" scenario).

Cases studied (2)

Feedstock	Based on market prices (€.GJ^{-1})	Reference	Self-dedicated production (€.GJ^{-1})	Reference	Maximum supply (kt.year^{-1})
Tallow	14.1 (varying from 12.9 to 15.0)	FOB			207.9 (from 26 supplying municipalities
Soy oil	15.5 (varying from 14.8 to 16.6)	CIF	6.7 (varying from 5.0 to 10.0)	CIF	1,946.1 (production around Presidente Venceslau)
Palm oil	14.8	CIF	12.8 (varying from 12.3 to 13.3)	CIF	387.6 (production around Alto Araguaia)
Macaw oil			10.4 (varying from 7.5 to 14.4)	CIF	514.1 (production around Itarumã)

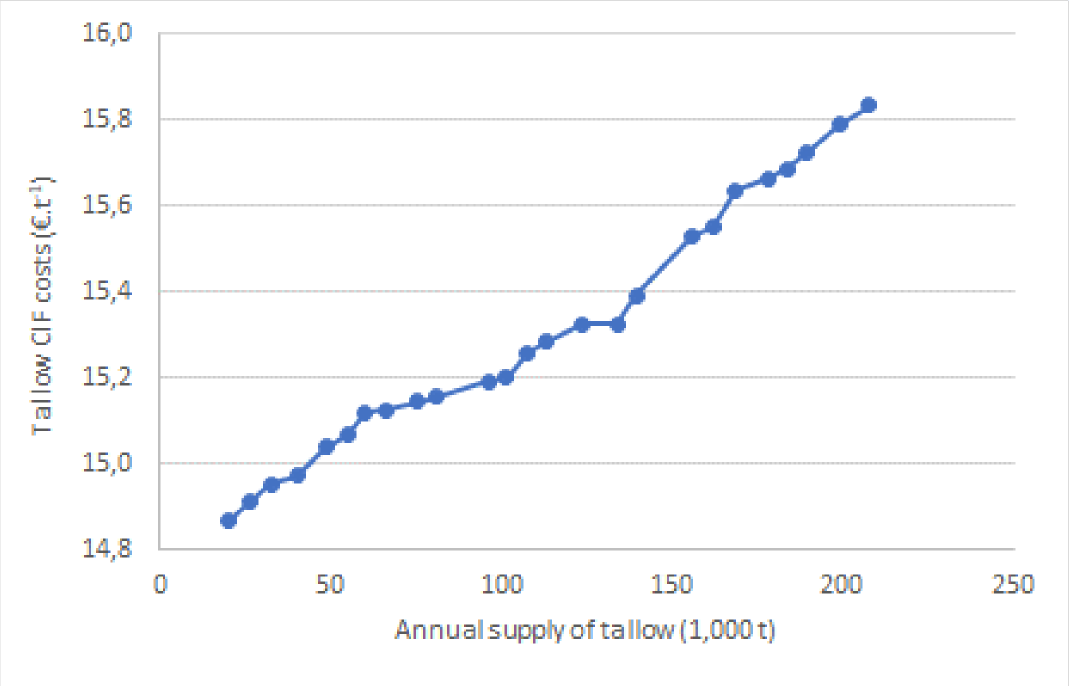
- As in the other HEFA case studies, five different capacities of SAF production were considered, varying the output from 20.3 to 300.1 t.day^{-1} of SAF (140.3 to 2075.0 t.day^{-1} of hydrocarbons). Coherent with the hypotheses used in other case studies, the required raw material varies from 61.1 to 906 kt.year^{-1}.
- It was assumed that each raw material contributes equally to the supply needed in each case (for the largest industrial capacity, the share of tallow would be slightly lower than 25%).

Vegetable oil transported by rail



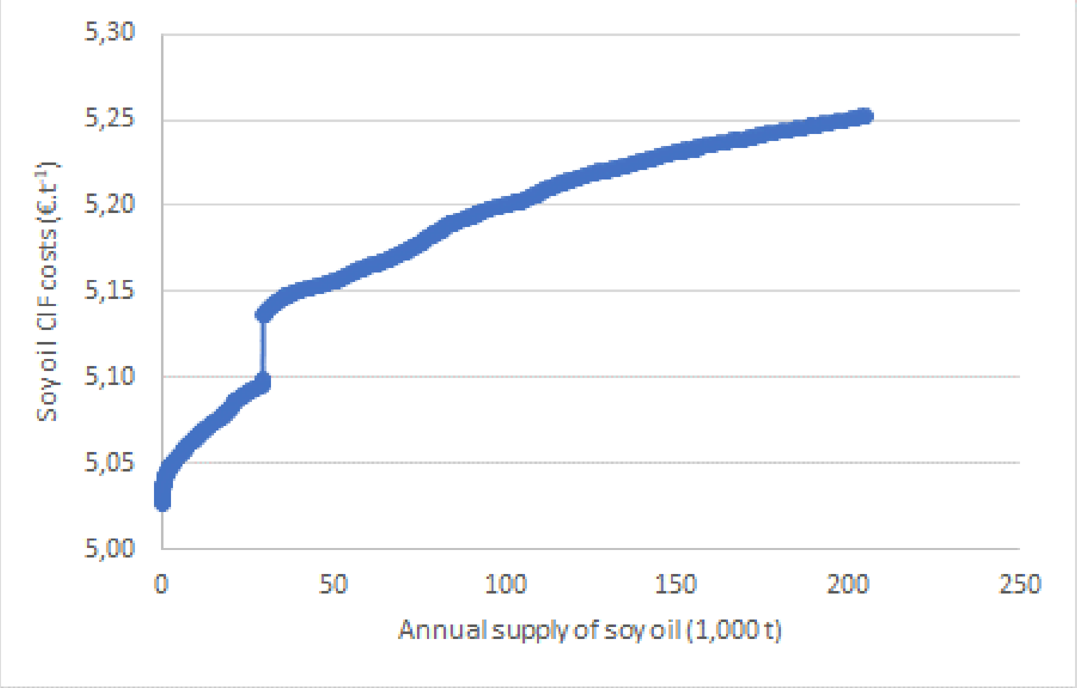
- The figure shows the existing rail network in Brazil in 2017 and the three sites where it was assumed the production of soy, macaw and palm oil. The production in these three sites was addressed in details in each specific case study.
- Soybean it would produced around Presidente Venceslau (SP), and oil extraction would be in there. Oil would be transported by train to REVAP.
- As for palm oil, the production would be around and the extraction in Alto Araguaia (south of Mato Grosso). Transport would be train.
- Finally, in the case of macaw oil, fresh fruits would be produced around Itarumã (GO), and the extraction at the city. Oil would be transport by truck to Cassilândia (MS), and them by train to REVAP.

Tallow supply at REVAP



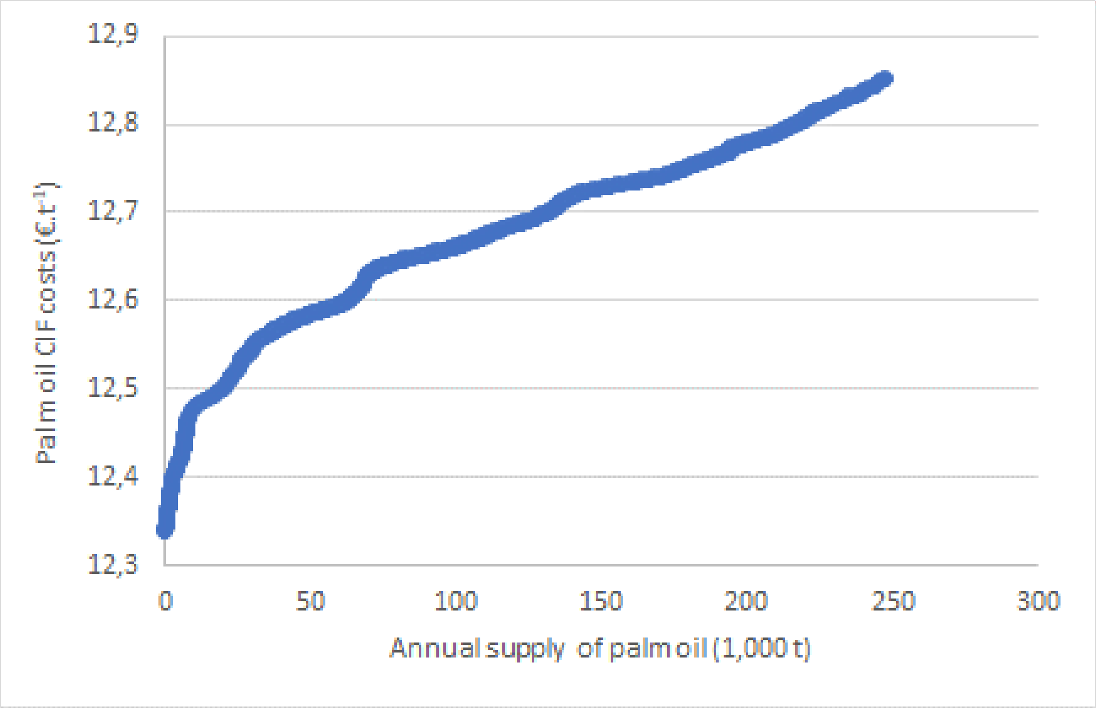
- The figure shows the maximum supply curve at REVAP, assuming that the transport from each of the 26 municipalities to the industrial plant would be done by truck. The maximum tallow supply would be 207.9 thousand $t.year^{-1}$, enough to contribute almost 25% of the supply of raw material needed in the case of the largest industrial plant (2,075 t of hydrocarbons per day, i.e. 300.1 $t.day^{-1}$ of SAF).
- The CIF cost of tallow is the average market price in 2018, plus freight costs from each municipality to REVAP. Freight represents 4% to 11% of CIF costs.
- Due to the assumed hypothesis, the logic of using tallow would not be to minimize production costs, but rather to minimize risks. It is also considered that the contribution of tallow would have an appeal for improve sustainability, despite its market prices being very close or even higher (considering freight) to the CIF costs of vegetable oils.

Supply of soy oil at REVAP



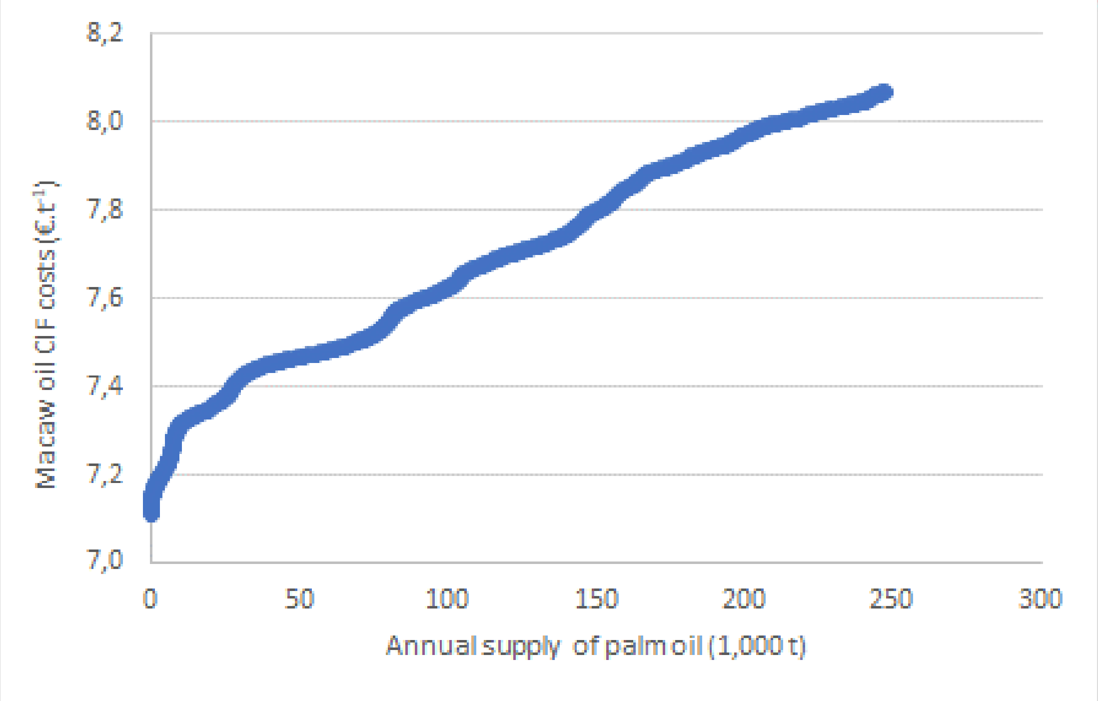
- The figure shows the supply curve for soy oil at REVAP, assuming the self-dedicated production and the transportation from Presidente Venceslau (SP) (where oil would be extracted) by trains.
- The maximum supply needed would be 205.3 thousand $t.year^{-1}$, enough to contribute 25% of the supply of raw material needed in the case of the largest industrial plant (2,075 t of hydrocarbons per day, i.e. 300.1 $t.day^{-1}$ of SAF). This amount represents less than 11% of the maximum estimated supply for a productive pole in Presidente Venceslau and surroundings.
- Self-dedicated soy oil production would be the cheapest option for SAF production. Alternatively, considering that soy oil would be valued at market prices (based on average figures in 2018), the CIF cost would be 15.5 $€.GJ^{-1}$, making soy oil the most expensive option.

Supply of palm oil at REVAP



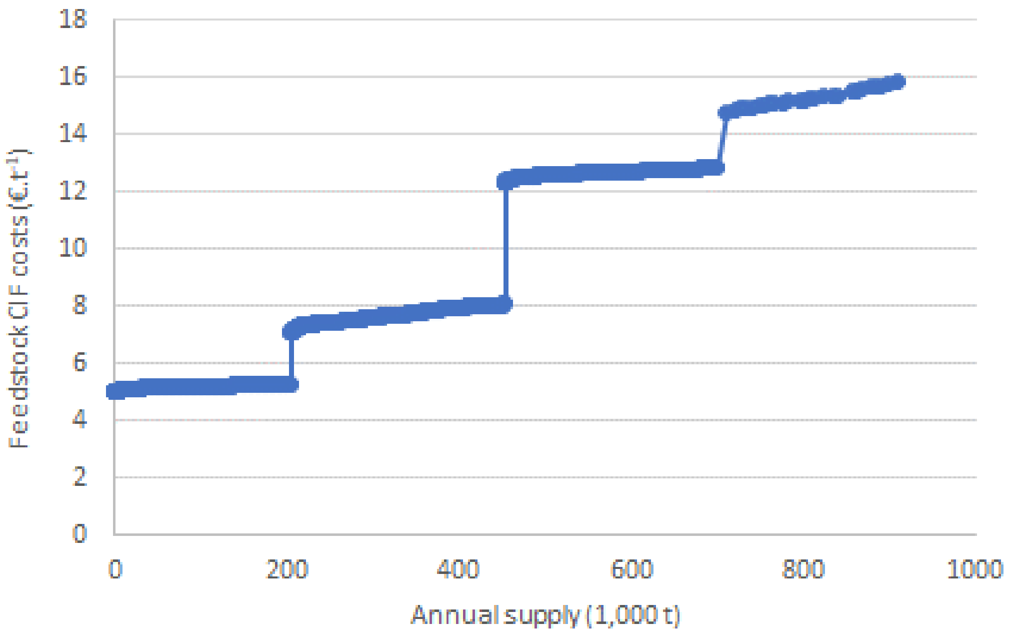
- The figure shows the supply curve for palm oil at REVAP, assuming the self-dedicated production and the transportation from Alto do Araguaia (MT) (where oil would be extracted) by train.
- The maximum supply needed would be 246.4 thousand $t.year^{-1}$, enough to contribute 25% of the supply of raw material in the case of the largest industrial plant (2,075 t of hydrocarbons per day, i.e. 300.1 $t.day^{-1}$ of SAF). This amount represents 64% of the maximum estimated supply for a productive pole in Alto do Araguaia and surroundings.
- Compared to other feedstocks, self-dedicated palm oil production would be an intermediate option. It would be the third in the ranking, in both price scenarios. This is because the average market price in 2018 is not far from the costs of self-dedicated production.

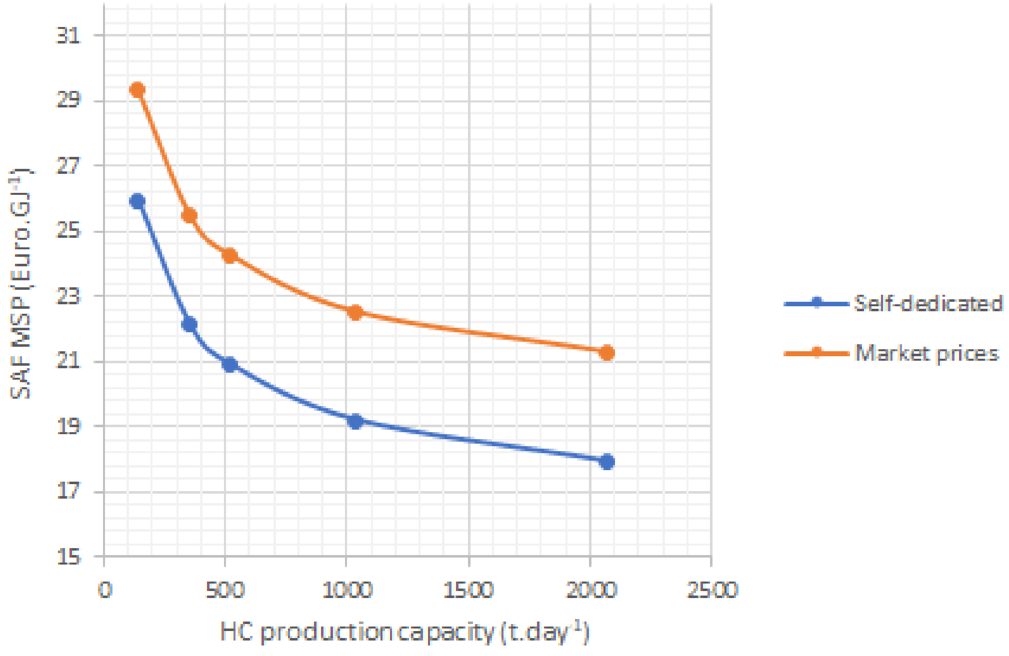
Supply of macaw oil at REVAP



- The figure shows the supply curve for macaw oil at REVAP, assuming the self-dedicated production and the transportation by trucks from Itarumã (GO) (where oil would be extracted) to Cassilândia (MS) (where oil would be shipped), and finally by train to REVAP .
- The maximum supply needed would be 246.4 thousand t.year^{-1}, enough to contribute 25% of the supply of raw material in the case of the largest industrial plant (2,075 t of hydrocarbons per day, i.e. 300.1 t.day^{-1} of SAF). This amount represents 49% of the maximum estimated supply for a productive pole in Itarumã and surroundings.
- In the “self-dedicated” scenario, compared to other feedstocks, self-dedicated macaw oil production would be the second cheapest option (the cheapest in the other scenario). As mentioned, due to the almost non-existent market, the opportunity cost alternative was not considered.

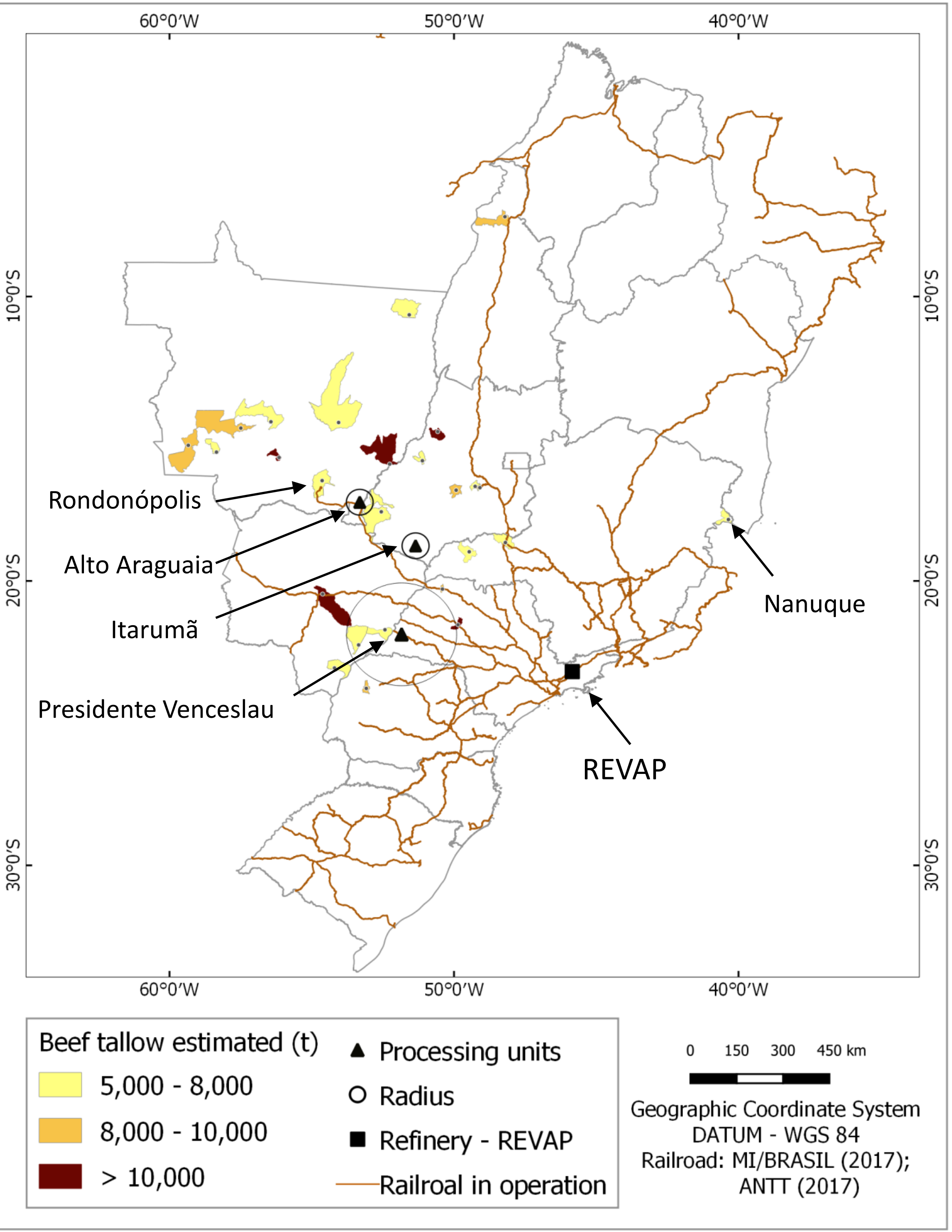
SAF production at REVAP





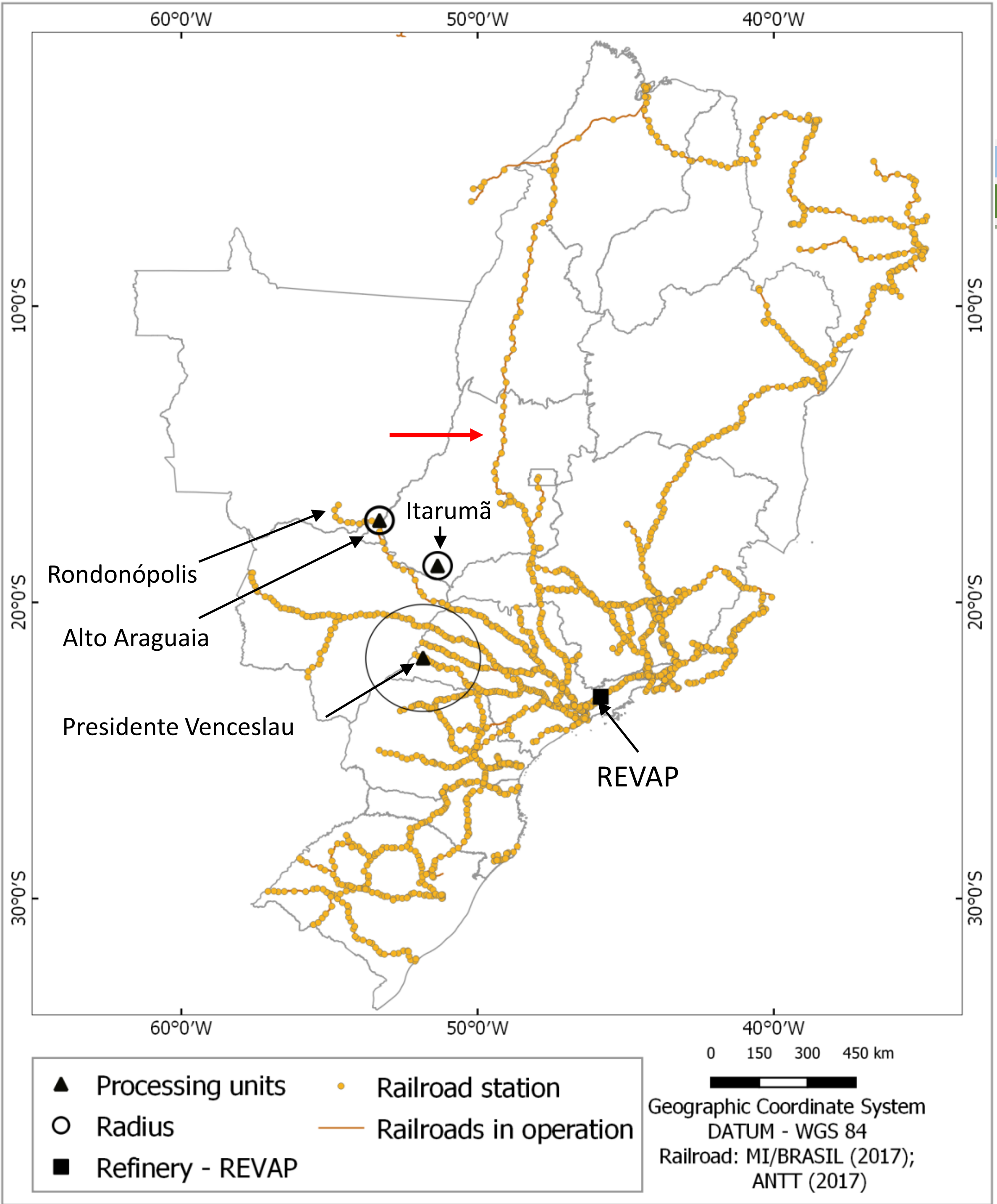
- The upper figure shows the combined supply curve at REVAP according to the assumption that each of the four feedstocks would contribute equally. The supply curve is for the production at the maximum industrial capacity, i.e. the production of 2,075 t of hydrocarbons per day, i.e. 300.1 t.day^{-1} of SAF.
- From left to right, the first segment if for soy, the second for macaw oil, the third for palm oil, and the last one for tallow.
- At the bottom the figure shows the estimated MSP (minimum selling prices) of SAF as function of the daily capacity of hydrocarbons production. The economic results are for the two scenarios previously mentioned: “self-dedicated” corresponds to the self-dedicated production of soy and palm oil and, consequently to the minimum CIF costs at REVAP; “market prices" corresponds to the scenario in which all raw materials are valued at market prices, except for macaw oil.
- The lowest MSP would be 17.9 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF) (in the self-dedicated case), being the difference 3.9 €.GJ^{-1} between the two scenarios.

Transporting tallow by train (1)



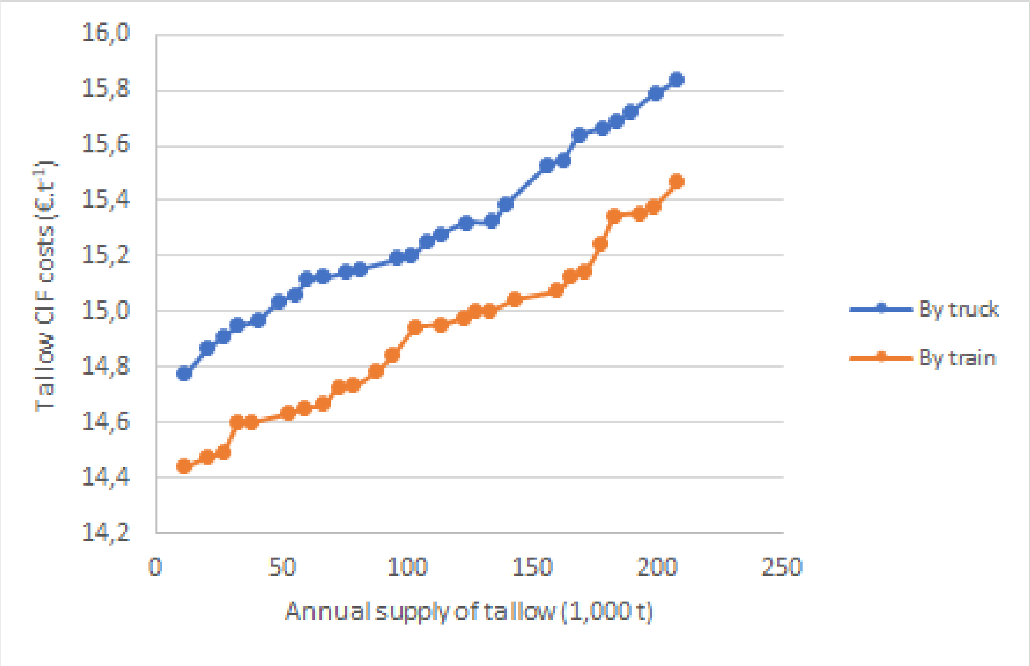
- According to the assumptions made, in one scenario tallow is the most expensive feedstock as long as market prices are assumed.
- On the other hand, SAF production from tallow probably has the lowest cost of avoided GHG emissions. Thus, aiming to improve the contribution of tallow, both from an economic and environmental point of views, a variant was considered, i.e. assuming it would be possible to transport tallow by train.
- The figure shows the railways close to where tallow would be available. The figure highlights the 26 municipalities that would be suppliers of tallow, according to the assumptions done here, and also highlights the processing sites of soy (P. Venceslau), palm (Alto Araguaia) and macaw (Itarumã).
- Out of the 26 municipalities where tallow would be available, Nanuque (MG) is the only one from which transport by train was considered unfeasible. It was assumed that the transport from Nanuque to REVAP would continue to be by trucks.

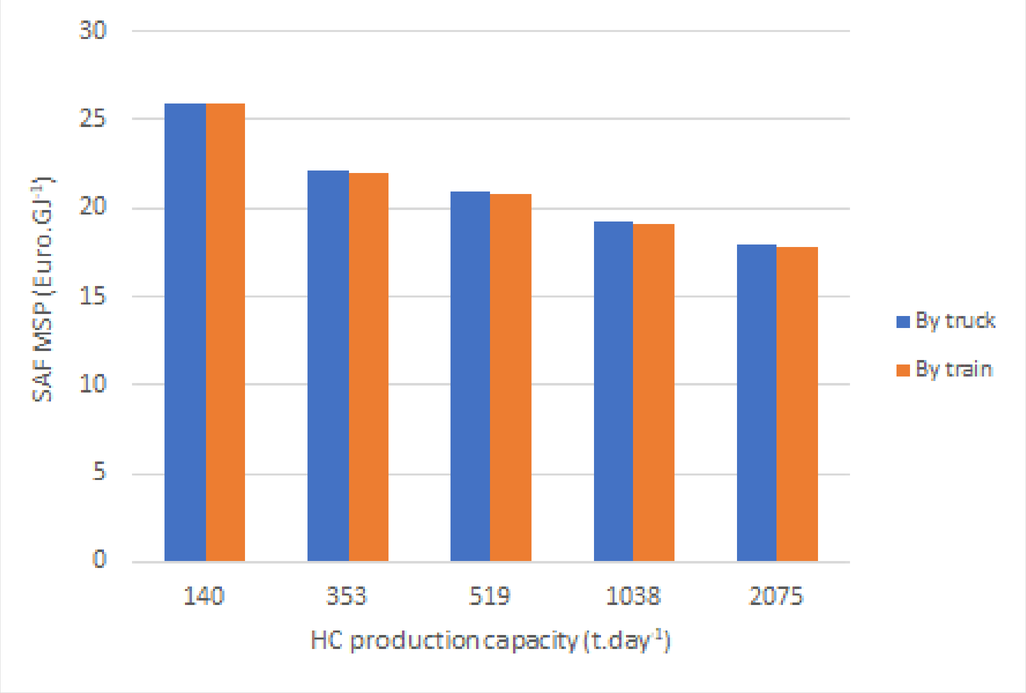
Transporting tallow by train (2)



- In nine of the producing municipalities considered (out of 26), the boarding would be in the municipality itself. In the case of 16 municipalities it would be necessary to transport tallow by truck from the production site to the train boarding point, with the distances varying from 66 to 660 km.
- Rondonópolis (MT) would become a tallow transport hub, concentrating 30% of the shipment of what would be transported on trains. Summing with the shipments in Alto Araguaia (MT), almost 40% of the estimated tallow production would flow through this railroad.
- In addition, the railroad that connects Rondonópolis to REVAP also passes through Alto Araguaia (where palm oil production would be shipped) and Cassilândia (MS) (to where the production of macaw oil processed in Itarumã (GO) would transported). So, this would be the main input supply line to REVAP.
- Presidente Venceslau (SP) would also be an important hub, since about 10% of the tallow production would be shipped there, in addition to the shipment of all the soy oil processed in the municipality.
- The railroad that connects the north (e.g. Tocantins) with the southeast (REVAP) (indicated by a red arrow in the figure) would allow the flow of tallow produced in north of Mato Grosso, Goiás and Minas Gerais.

SAF production: additional results





- The upper figure shows the new tallow supply curve at REVAP, in the case of transporting the feedstock by train (except from Nanuque). The reduction of CIF costs varies from 0.35 to 0.42 €.GJ^{-1}, depending on the segment of the supply curve.
- The second figure shows the estimated MSP (minimum selling prices) of SAF as function of the daily capacity of hydrocarbons production. The results are for the "self-dedicated" case, i.e. the self-dedicated production of soy and palm oil and, consequently to the minimum CIF costs at REVAP.
- It can be seen that the impact of tallow transport by train on the SAF MSP is irrelevant, representing less than 1%
- The lowest MSP would be 17.8 €.GJ^{-1} for the production of 2,075 t of hydrocarbons per day (300.1 t.day^{-1} of SAF) (in the self-dedicated case).

Analysis of the results (1)

- Table presents the best result for combined supply (bottom line), and compares this with results presented in previous case studies.
- In order to keep coherence for comparison, the sites of production are the same assumed in the combined supply case.
- The comparison with the results of the palm oil case study is hampered by the fact that it is not possible to supply oil, exclusively from Alto Araguaia, to the largest industrial plant (SAF production of 300.1 $t.day^{-1}$).

Feedstock	MSP ($€.t^{-1}$)	MSP ($€.GJ^{-1}$)	Case
Soy oil	548.0	12.8	Production around P. Venceslau/by trucks[1]
Macaw oil	748.8	17.5	Production around Itarumã/by trucks[2]
Palm oil	1,023.8	23.9	Production around Alto Araguaia/by train[3]
Combined supply	763.6	17.8	Different supply sites/transport by train[4]

[1] Self-dedicated production of soy oil, aiming to minimize feedstock cost; oil transported to REVAP by trucks.
[2] In estimating the potential production of fresh fruits, no restrictions were imposed.
[3] Palm oil transported by train from Alto Araguaia to REVAP; SAF production of 75 $t.day^{-1}$ due to the lack of palm oil.
[4] Combined supply from four different sites; it is considered maximum transport of all feedstock by train.

- In the table above, all results are for SAF production at REVAP.
- In case studies related to the use of soy and macaúba oil as a raw material, transport by train from the place of supply to the oil refinery was not considered. However, as the cost of freight has a moderate impact on economic results (based on the MSP), there is no significant distortion in the comparison. In other words, the comparison is possible.
- It can be concluded that, exclusively from an economic point of view, there is no appeal in the combination of raw materials, i.e. there is no significant reduction in the SAF MSP. The main motivations would be, first, to reduce supply risks and, second, to make the use of tallow feasible in larger production units. As mentioned, the use of tallow would have an environmental appeal, due to the smaller carbon footprint.

Analysis of the results (2)

- Table presents the best result for combined supply when market prices for soy and palm oil are considered. The comparison is with equivalent cases, except for macaw oil.
- As previously mentioned, the comparison with the results of the palm oil case study is hampered by the fact that, exclusively from Alto Araguaia, it is not possible to supply oil to the largest industrial plant (SAF production of 300.1 $t.day^{-1}$).

Feedstock	MSP ($€.t^{-1}$)	MSP ($€.GJ^{-1}$)	Case
Soy oil	1,071	23.8	Market prices & exported soy oil[1]
Macaw oil	749	17.5	Production around Itarumã/by trucks[2]
Palm oil	1,129	26.4	Production around Alto Araguaia[3]
Combined supply	912	21.3	Different supply sites/transport by train[4]

[1] The feedstock is exported soy oil (figures for 2018), considering the market price that year.

[2] In estimating the potential production of fresh fruits, no restrictions were imposed.

[3] SAF production of 75 $t.day^{-1}$ due to the small potential production of palm oil at this site. Market prices of palm oil in 2018 were considered.

[4] Combined supply from four different sites; it is considered maximum transport of all feedstock by train.

- All results are for SAF production at REVAP.
- Compared with the options of producing SAF exclusively from soy and palm oil, when both feedstocks would be valued by marked prices, there is a clear advantage of combined supply. However, macaw oil is the feedstock that allows reduction in the MSP, and not tallow.
- Other obvious positive aspects to consider are reductions in supply risk (due to physical restrictions) and of the risk associated with price volatility.
- In summary, the inclusion of tallow in the basket of raw materials has (potentially) environmental appeal, while the inclusion of macaw oil has the potential to improve economic viability. The inclusion of soybean oil in the basket potentially reduces the risk of scarcity.

Analysis of the results (3)

- 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.

Feedstock	MSP (€.t^{-1})	MSP (€.GJ^{-1})	Case
Combined supply	764	17.8	Self-dedicated production of soy and palm oil[1,2]
Combined supply	912	21.3	Soy and palm oil valued at market prices[2,3]

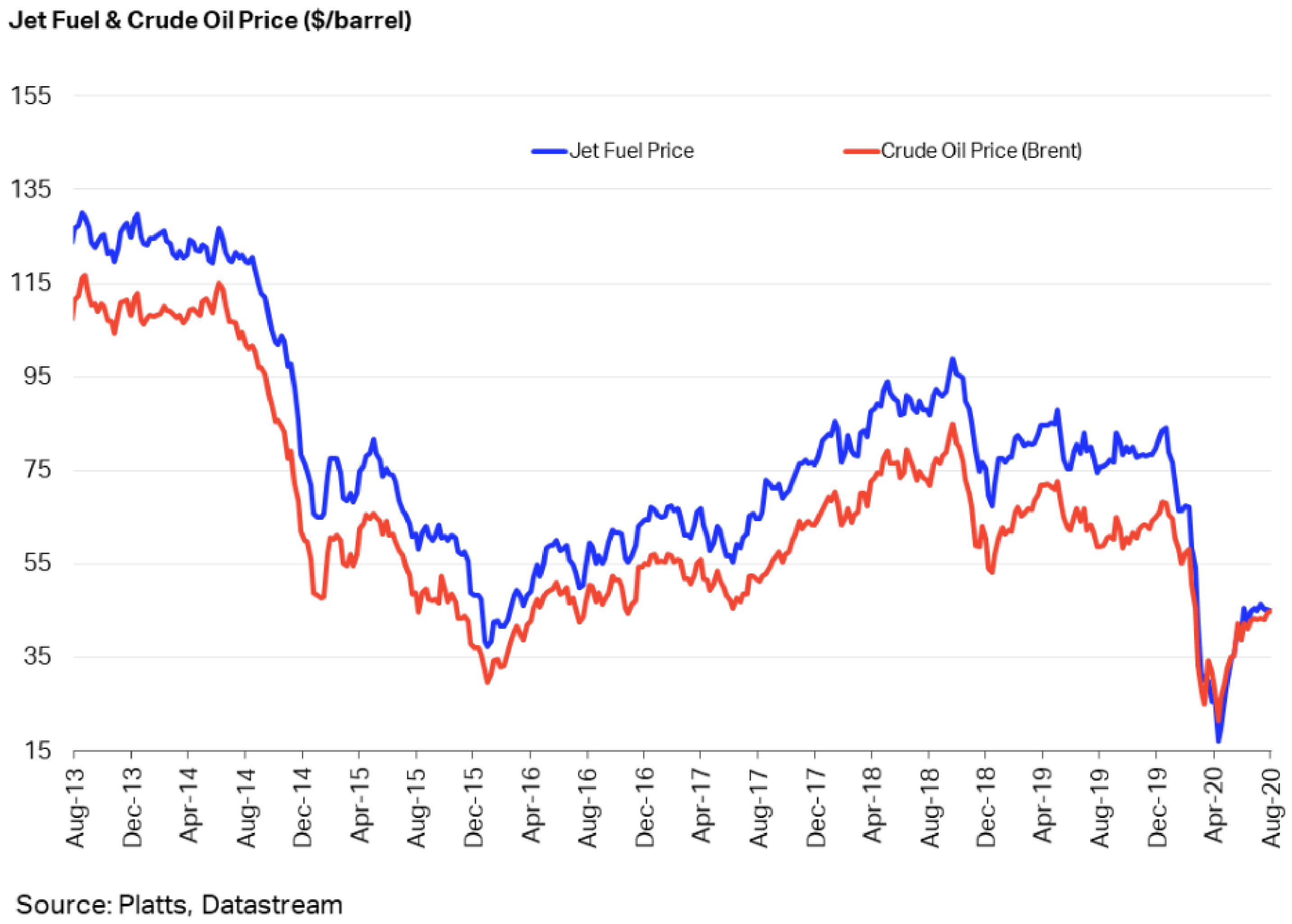
[1] Self-dedicated production of soy, palm and macaw oil was assumed, being the CIF costs at REPLAN estimated as function of the costs along the supply chain; transport from the supply site to REPLAN would be by train, as most as possible.

[2] Average market prices in 2018 were assumed for tallow.

[3] Average market prices in 2018 were assumed for soy and palm oil

- MSP results for combined supply 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 in Europe based on the HEFA-SPK pathway, from UCO (used cooking oil).
- In the same paper the authors mention the range 20-28 €.GJ^{-1} based on an literature survey (papers published in 2012-2014); different feedstocks were reported in these papers, including tallow.
- Quoting De Jong et al. (2015), IRENA (2017) mentions 1,350 €.t^{-1} as the MSP of SAF from UCO.
- Also based on literature survey, Bosch et al. (2017) mention 1,300 €.t^{-1} as the estimate MSP for SAF production from UCO.
- Lang & Elhaj (2014) mention an IATA report (2013) that quotes estimated prices based on MIT modeling studies; in the case of bio-jet produced from tallow (nth plant; commercial volumes) the price would be 1,060 €.t^{-1}; our MSP estimate for the production of 20 t of SAF per day (the smallest industrial plant considered here) would be 1314 €.t^{-1}.

Comparing MSPs with jet fuel prices



- 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).

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

Analysis of the results (4)

- From a narrow point of view of economic viability, the high market prices for palm oil and beef tallow reduce the appeal of the combined supply. Based on market prices, most likely only the contribution of macaw oil - due to its not yet well established market - could have an advantage. However, there is no doubt about the benefits of diversification, which reduces the risks related to shortages and hedges to price volatility.
- In case it would be possible to go for dedicated production of soy oil, the benefits of the combined supply would be evident for a set of reasons, including lower MSP, lower risks and better hedging.
- The use of beef tallow has the potential benefit of a lower carbon footprint, as long as it is possible to be sure that no other issues related to livestock and slaughter could compromise the sustainability grade of the by-product.
- In addition, from the results presented here and in a previous report on the production of SAF from palm oil, there are doubts about the economic and environmental potential of this feedstock.
- Despite the fact that the impacts on the SAF MSP of transporting raw materials would be relatively small, it is obvious that the impacts on the carbon footprint could be considerable. It is important to highlight that the precariousness of the railway network in Brazil makes it necessary in many cases to have transport by truck over considerable distances in order to make possible the final transport by train. In this sense, it appears to be evident the necessary careful selection of production sites.

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) stricto sensu 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. However, sustainability schemes must demand the accomplishment to other sustainability principles.
- Here, the accomplishment of Principle 2 is assured by the fact that the production of all three vegetable oils would occur displacing pasturelands, in areas that were not converted after January 2008.
- Regarding Principle 1, the Default Life Cycle Emissions Value for the HEFA route based on soybean oil in Brazil indicates a Core LCA value of 40.4 $gCO_2eq.MJ^{-1}$, while the estimated ILUC LCA is 27.0, totalling 67.4 $gCO_2eq.MJ^{-1}$ of the bio-jet fuel. As the carbon footprint of the fossil jet fuel is 89 $gCO_2eq.MJ^{-1}$, avoided GHG emissions on life cycle basis would be 24.3%. The bio-jet fuel producer can evaluate the carbon footprint of its own production, and better results could be achieved both with low ILUC practices and transporting soy oil by railways. Obviously, an essential appeal of the combined supply would be taking advantage of the low carbon footprint of other feedstocks.

Conclusions

- The reported case study address the production of SAF combining four feedstocks: soy, palm and macaw oil, in addition to beef tallow.
- As for the economic viability of SAF production, the conclusion depends on the hypotheses of the valorization of raw materials. Considering market prices, a possible benefit is related only to the addition of macaw oil to the basket of raw materials. On the other hand, the self-dedicated production of soybean oil would have a significant impact, reducing the estimated minimum selling price (MSP). Regardless of the assumptions, reducing risks is a notable potential benefit.
- Adding beef tallow to the basket is not strictly economically advantageous. In addition, it is worth mentioning that a large part of the available tallow is already destined for the production of biodiesel. The appeal of beef tallow would be related to the aim of reducing the carbon footprint of SAFs.
- The conclusions of this case study, in addition to the specific case study for palm oil, reinforce the conclusion that palm is not a very promising biomass for the production of SAF in Brazil
- In this case study, the possibility of transporting the raw material by rail to the industrial plant where the SAF would be produced (at REPLAN) was explored. The impact on the estimated MSP is modest, but also because in rare cases it is not necessary to combine transport by truck with transport by train.

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

Case study: HEFA pathway / combined supply

Supplementary Material

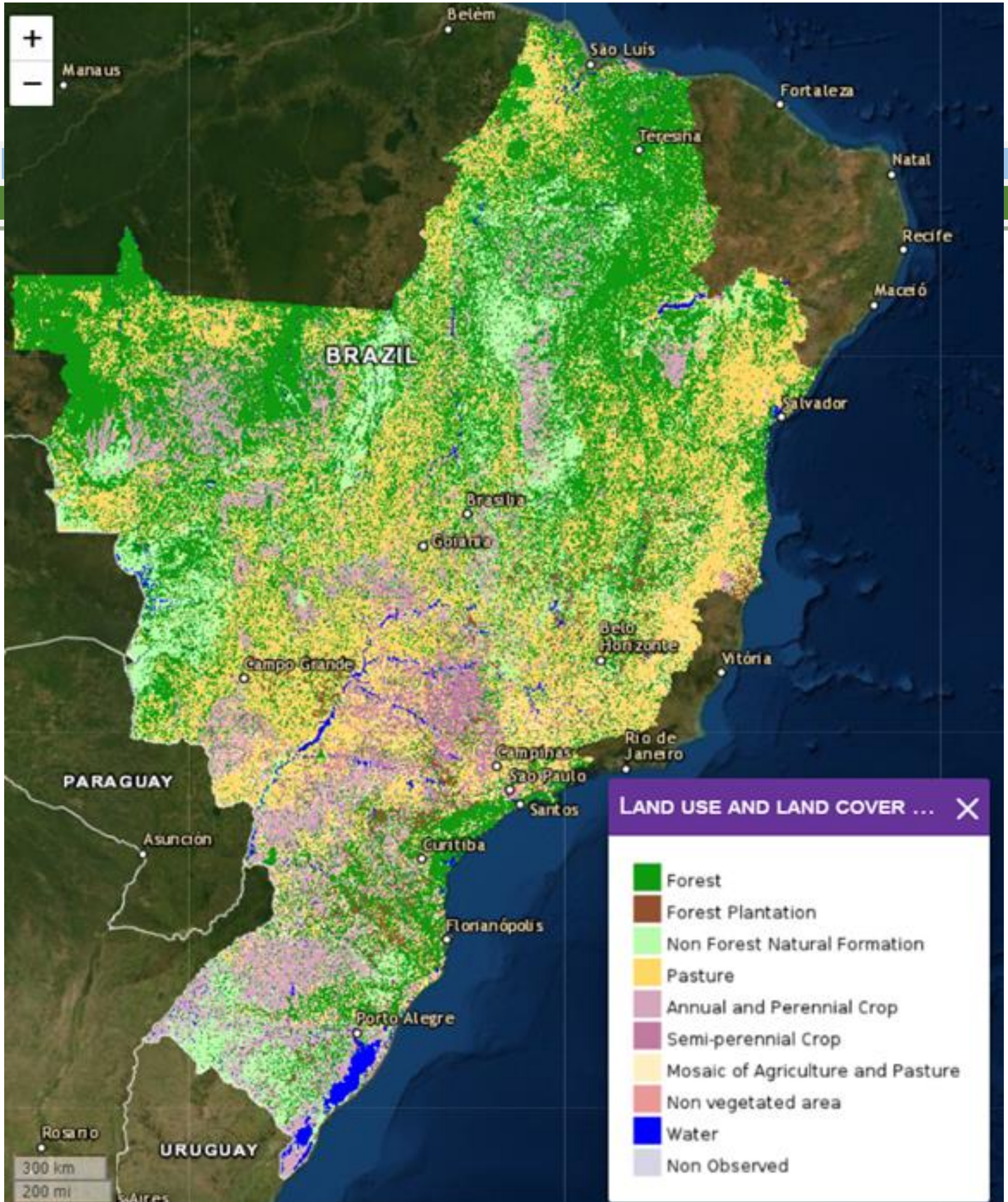
SAFmaps

UNICAMP

List of Contents

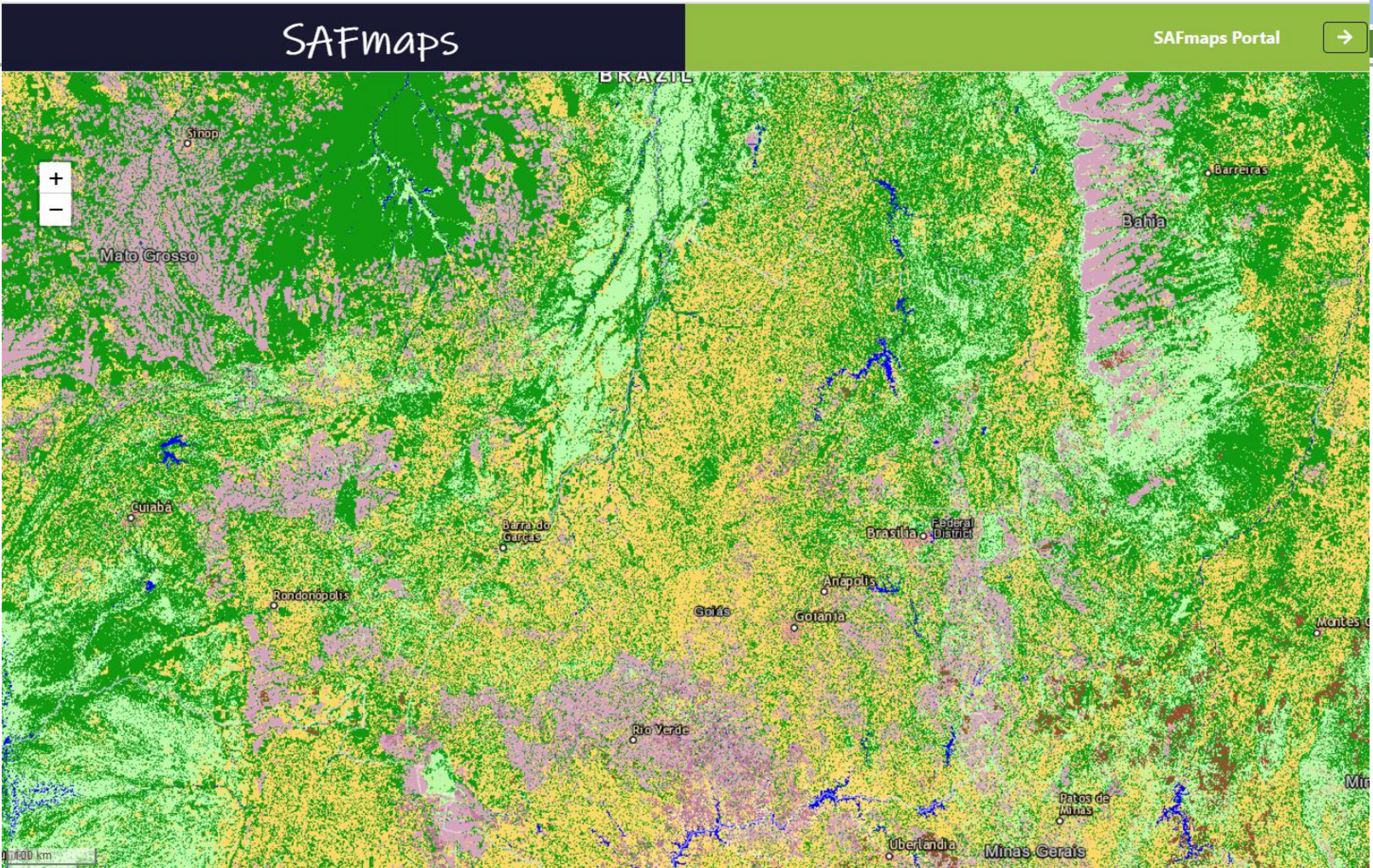
- Land use and land cover;
- Sensitive areas;
- Reported violations to land use and water use rights;
- Rail transport;
- Methodology for defining location and capacities of slaughterhouses;
- Jet fuel prices;
- About CORSIA and eligible fuels;
- Industrial costs.

Land use and land cover in 2018



- Information of land use and land cover available at the DBMS corresponds to 2018. The source is Mapbiomas.
- Figure shows the land use & land cover map available at the DBMS and used in this study. The image available at the DBMS 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 Centre-West, Brazil.

Land use and land cover in 2018 – image for Centre-West, Brazil



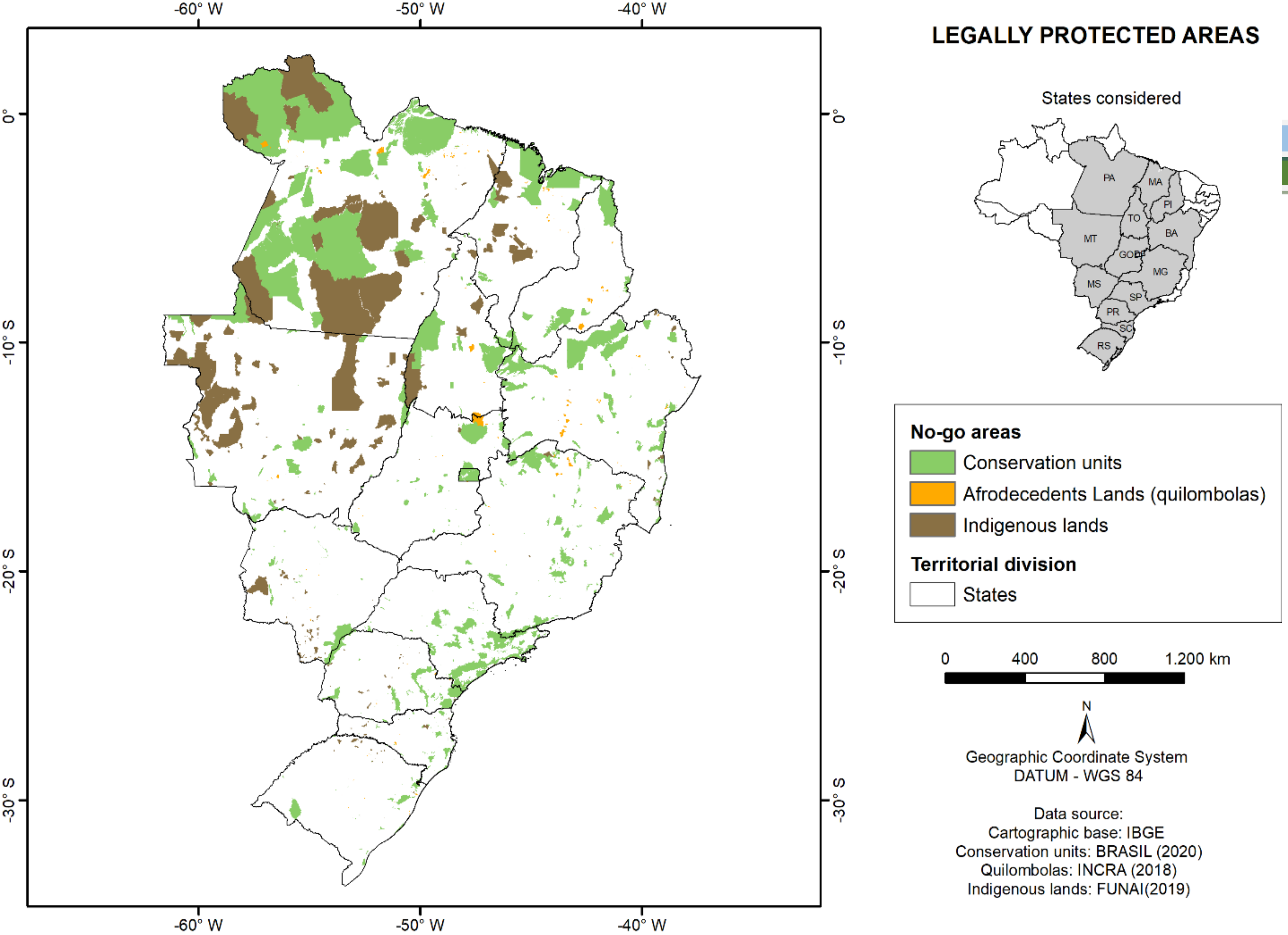
- Figure shows the land use & land cover map for Goiás and Mato Grosso.

Legend

Land use and land cover (2018)

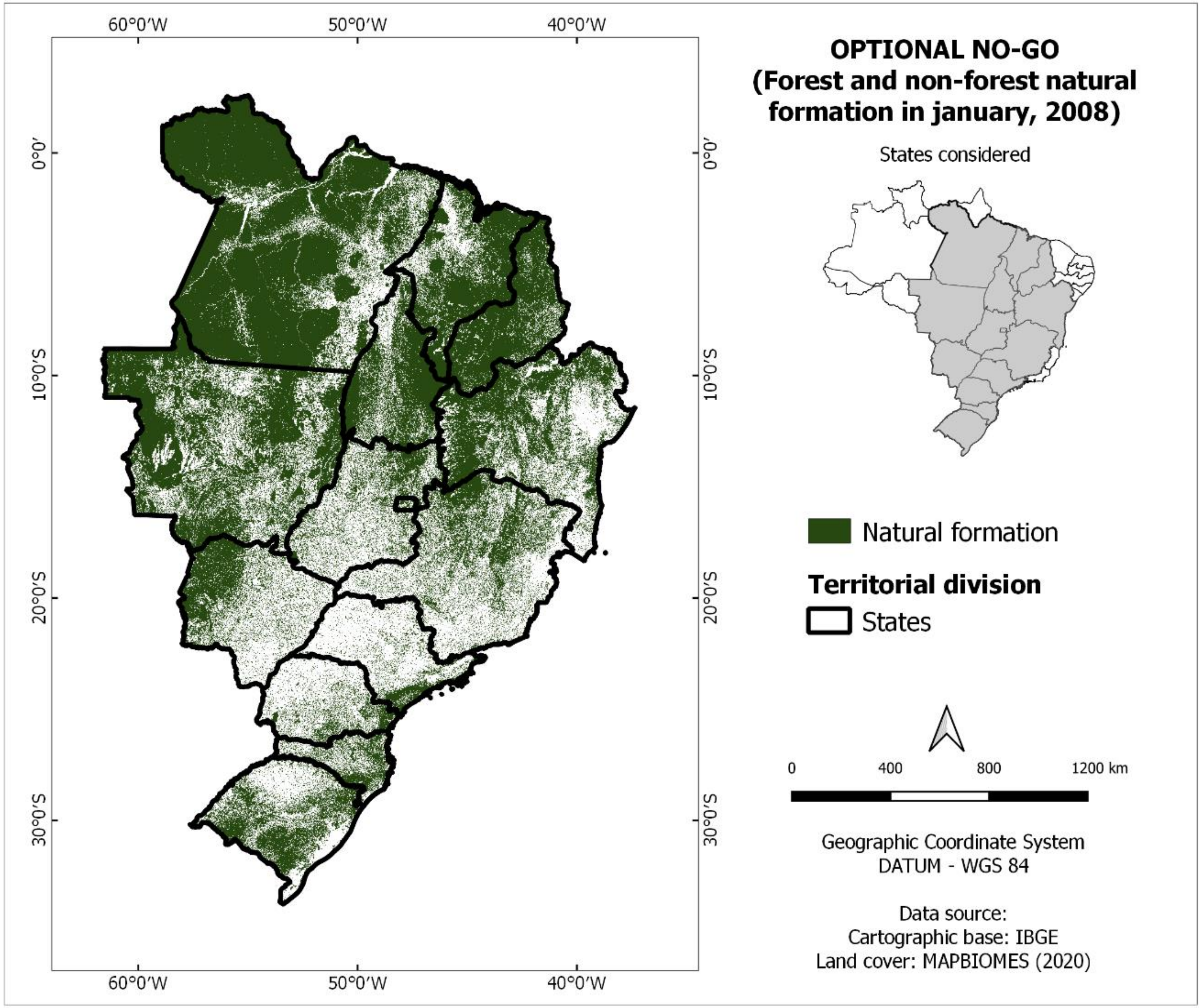
- Forest
- Forest Plantation
- Non Forest Natural Formation
- Pasture
- Annual and Perennial Crop
- Semi-perennial Crop
- Mosaic of Agriculture and Pasture
- Non vegetated area
- Water
- Non Observed

Sensitive areas (1)



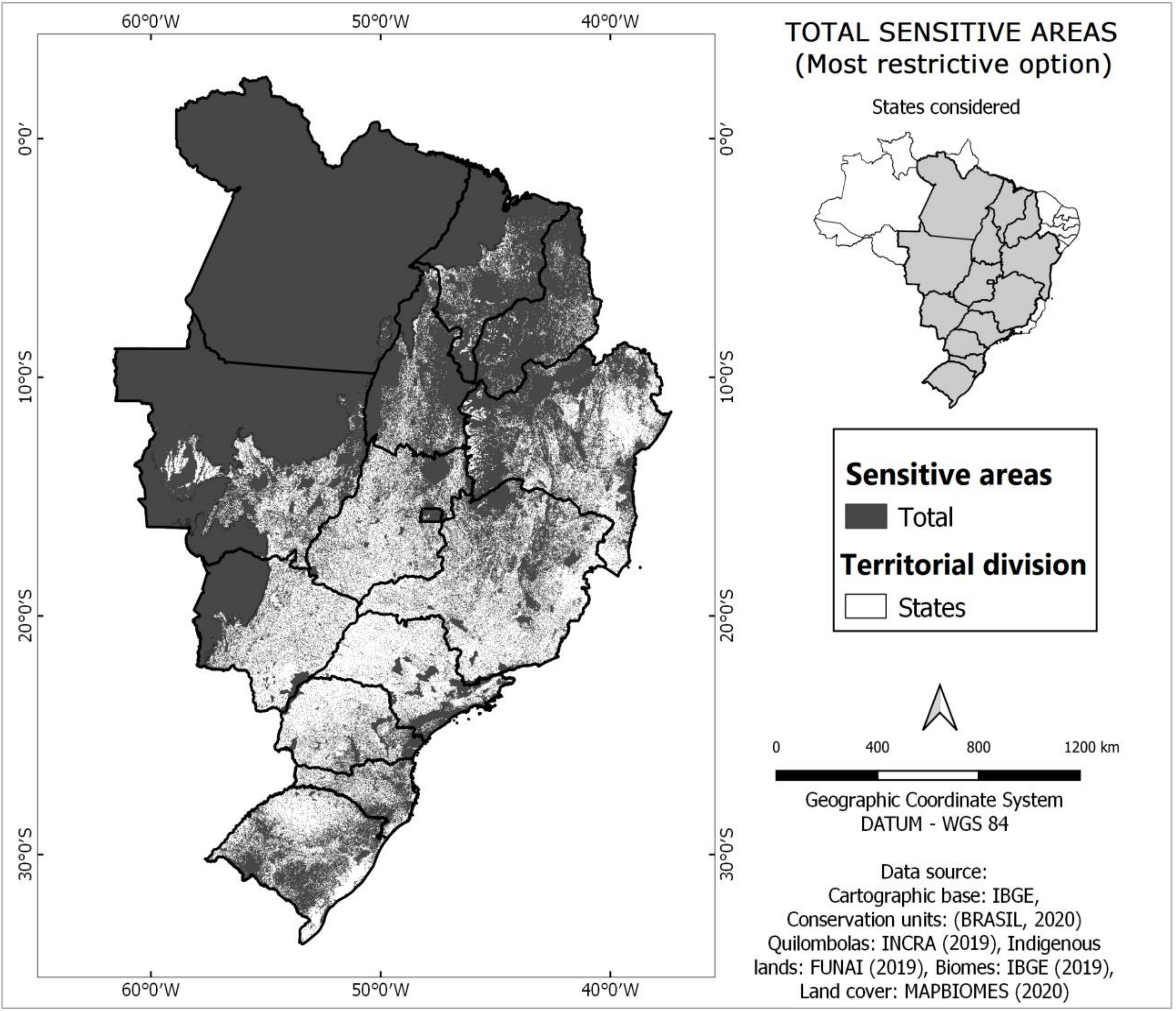
- Feedstock production cannot occur in legally protected areas.
- Legally protected areas include conservation units (for environmental reasons), the land that belongs to Afro-descendants (i.e. quilombola areas, or Afro-Brazilian settlements) and reserves of indigenous peoples.

Sensitive areas (2)



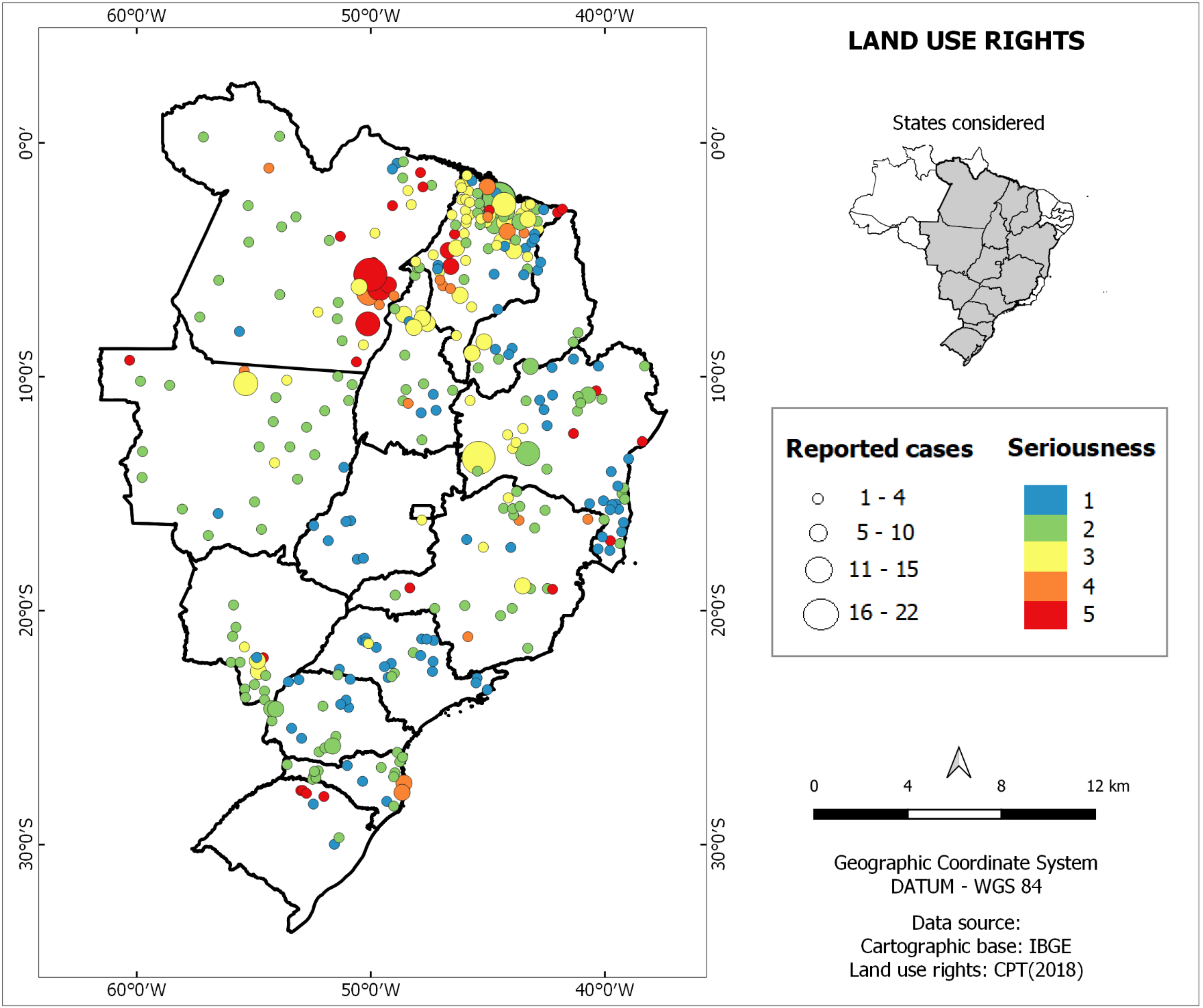
- According to CORSIA, SAF cannot be made from feedstocks obtained in certain areas (for example, primary forests, wetlands, etc.) where land was converted after January 1, 2008 (see information about CORSIA).
- In this sense, a map of land uses and land cover by the end of 2007 was used to define - 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)

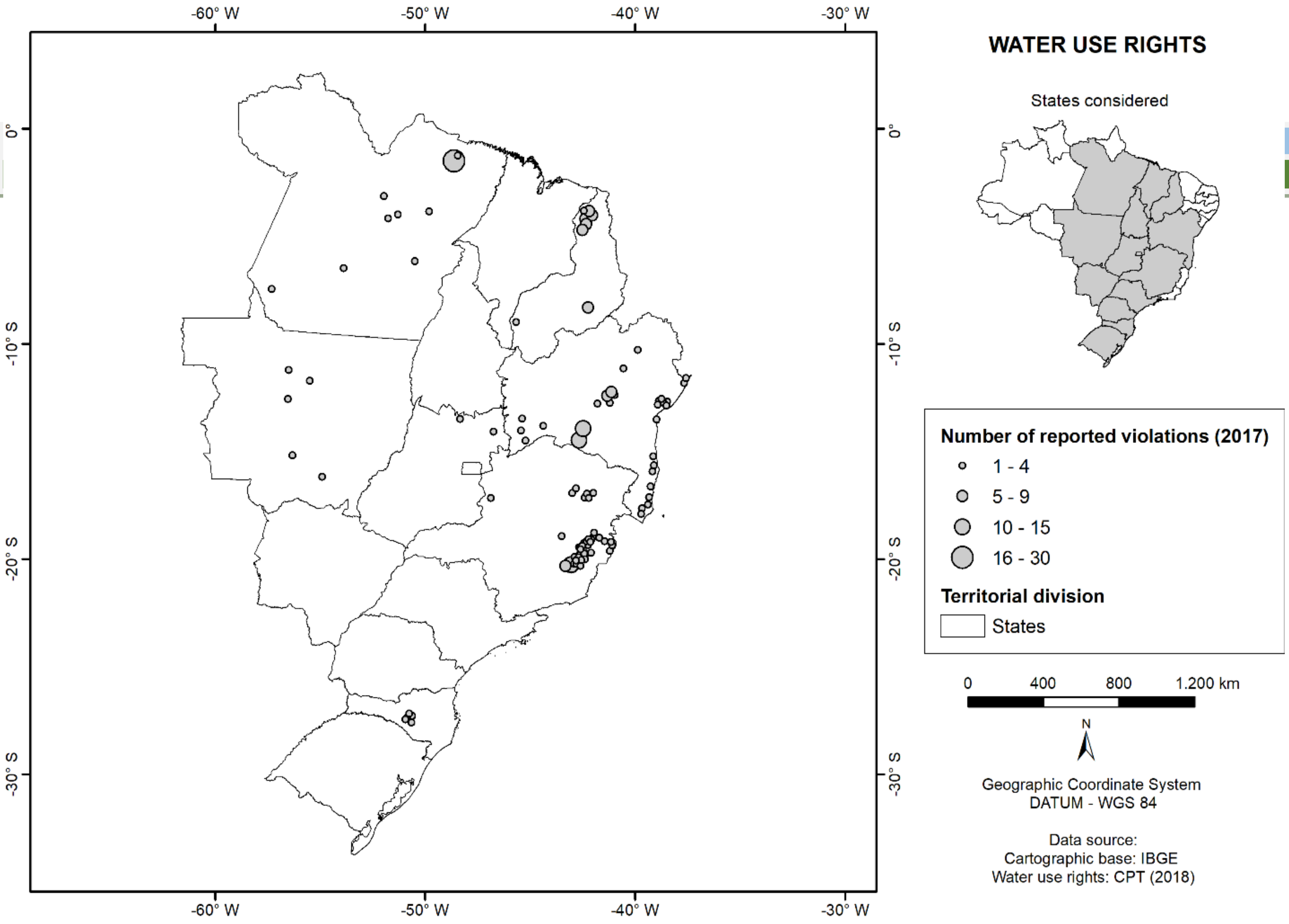


- The figure combines the previous map with areas of the biomes Amazon Forest and Pantanal, which are biodiversity hot-spots.
- In this project, this is the most restrictive option.
- Both maps include, as unusable areas for feedstock production, the lands classified as national parks, areas protected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

SAFmaps

- 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).

Location and capacities of slaughterhouses

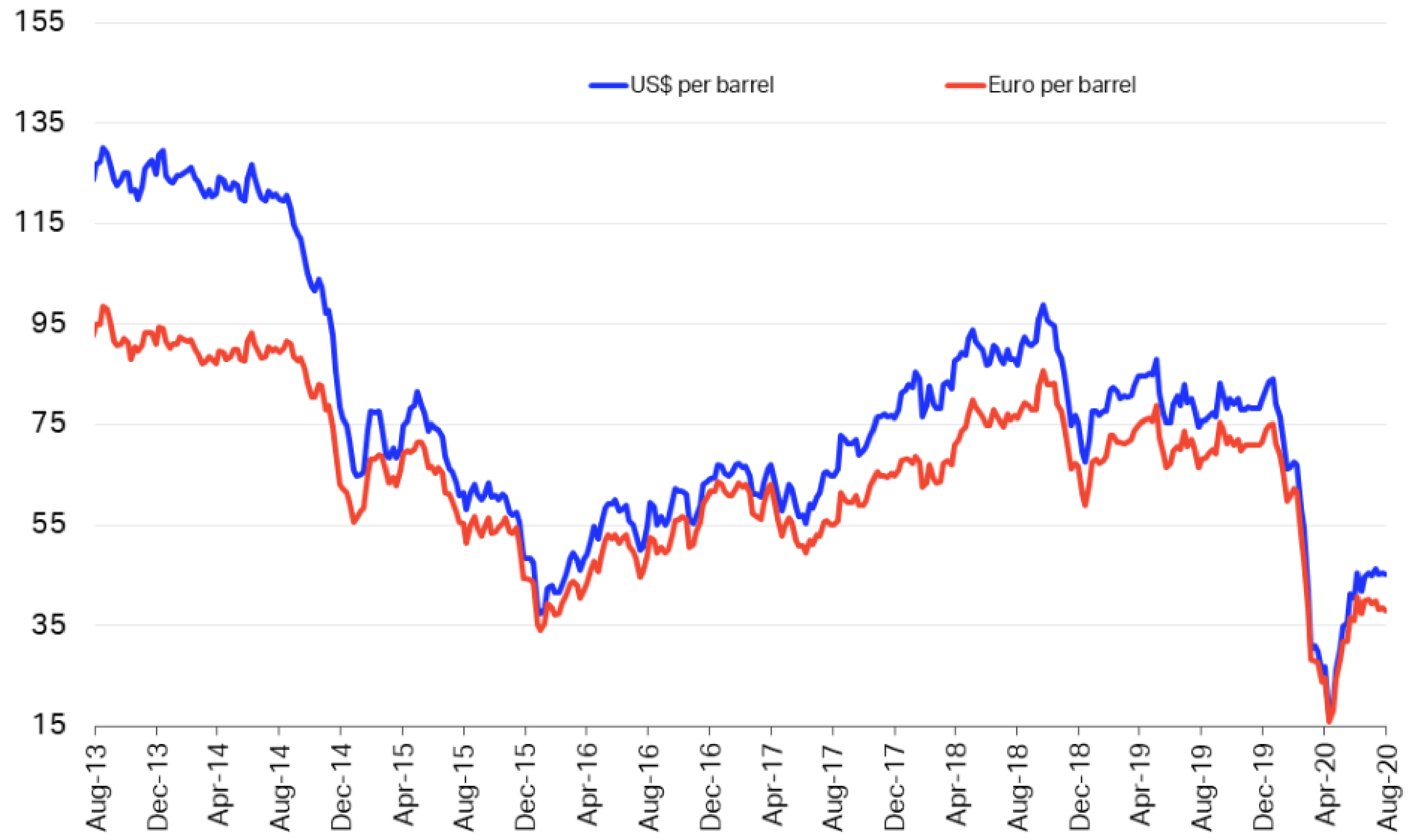
- The classification procedure was defined by Agroicone (in the context of the project Mapping Feedstocks Availability for Sustainable Aviation Fuels Production in Brazil), with support of the Unicamp's team. The procedure combines information on location and capacities of slaughterhouses inspected by SIF (the sources are LAPIG (2017) and MAPA (2019)), and data on slaughters, which are available only on state basis (IBGE, 2018). For distributing slaughters per municipality it was defined a correlation procedure based on the data on employment related to cattle slaughters (i.e. slaughters allocated in proportion to employees per municipality), provided by MTE – Labour Department (2018).
- It was possible to apply the allocation procedure to 14 states, covering about 95% of the total number of slaughters in 2019; it is estimated that in these states there are 439 slaughterhouses, in 172 municipalities.
- Once the allocation procedure was applied, it was possible to estimate the availability of beef tallow in 2019 (totalling 530.4 thousand tonnes) (the yield assumed is 0.088 t of tallow per tonne of carcass slaughtered, according to Garcilasso (2014)). From the total, the sample selected for the case study reported here corresponds to the availability of 207.9 thousand tonnes of beef tallow, in 26 municipalities.

Rail transport

- In order to estimate the cost of transporting feedstocks 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 extraction site and the SAF industrial production unit (REPLAN) 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, 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.

Jet fuel prices: historical data and worldwide variations

SAFmaps



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)

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