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

# Case study: HEFA pathway / soybean

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

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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 soybean oil. Three cases were explored, considering both the soy oil already available (and the current soy production) and the expansion of soy cultivation. For the already available soy oil, only SAF production at REVAP, in Southeast, was considered. For the oil that can be produced from the soybean already available, and also from the expansion of soybean cropping, SAF could be produced both at REVAP and RNEST (in the Northeast). In case of soybean expansion, it was considered self-dedicated cropping in three sites (Brumado (BA), Paranaíba (MS) and Presidente Venceslau (SP)); the potential around Brumado is lower compared to the other two sites.
- The cases mentioned above imply different hypotheses of setting value to soy oil. When the oil is valued according to its market prices, the estimated minimum selling price (MSP) of SAF is higher, varying from 24 to 32 €.$GJ^{-1}$ (1,017-1,371 €.$t^{-1}$). The best results are for self-dedicated production of soy oil, in a hypothetical vertical supply chain; in these cases, the MSP would vary from 13 to 21 €.$GJ^{-1}$ (547 to 897 €.$t^{-1}$), depending on the industrial scale.
- Even for a relatively small production of SAF, as considered here (less than 3% of the Brazilian consumption of jet-fuels in 2018), a large amount of soy would be needed - and, of course, soy oil. Thus, it would be convenient to consider the combination of feedstocks, an alternative that would reduce risks. This hypothesis was addressed in one of the case studies (HEFA – combined supply).

# Summary

- About the pathway;
- Soy production in Brazil;
- Cases studied;
- Soy suitability (procedure, validation and results);
- Soy productivity;
- Results, analysis & comparisons;
- Conclusions;
- References;
- Supplementary Material.

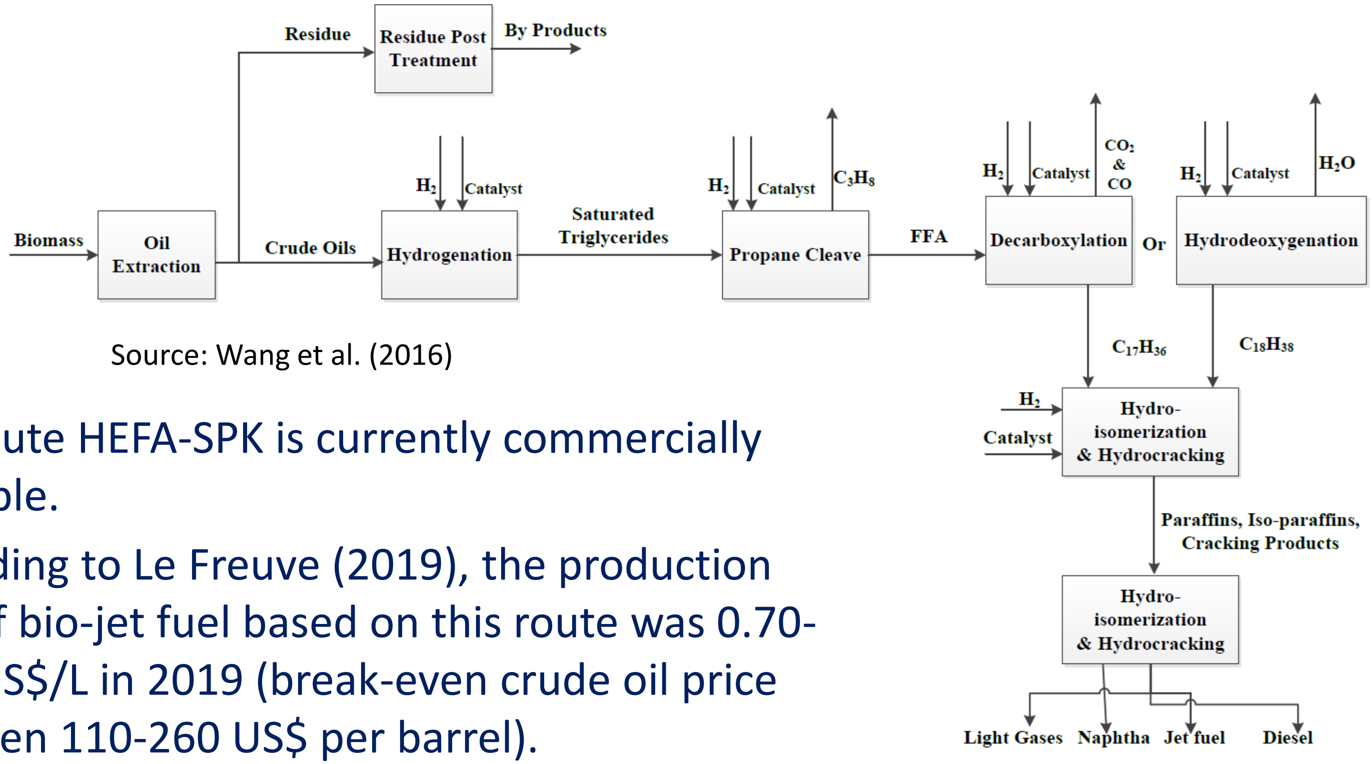
# About the pathway

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

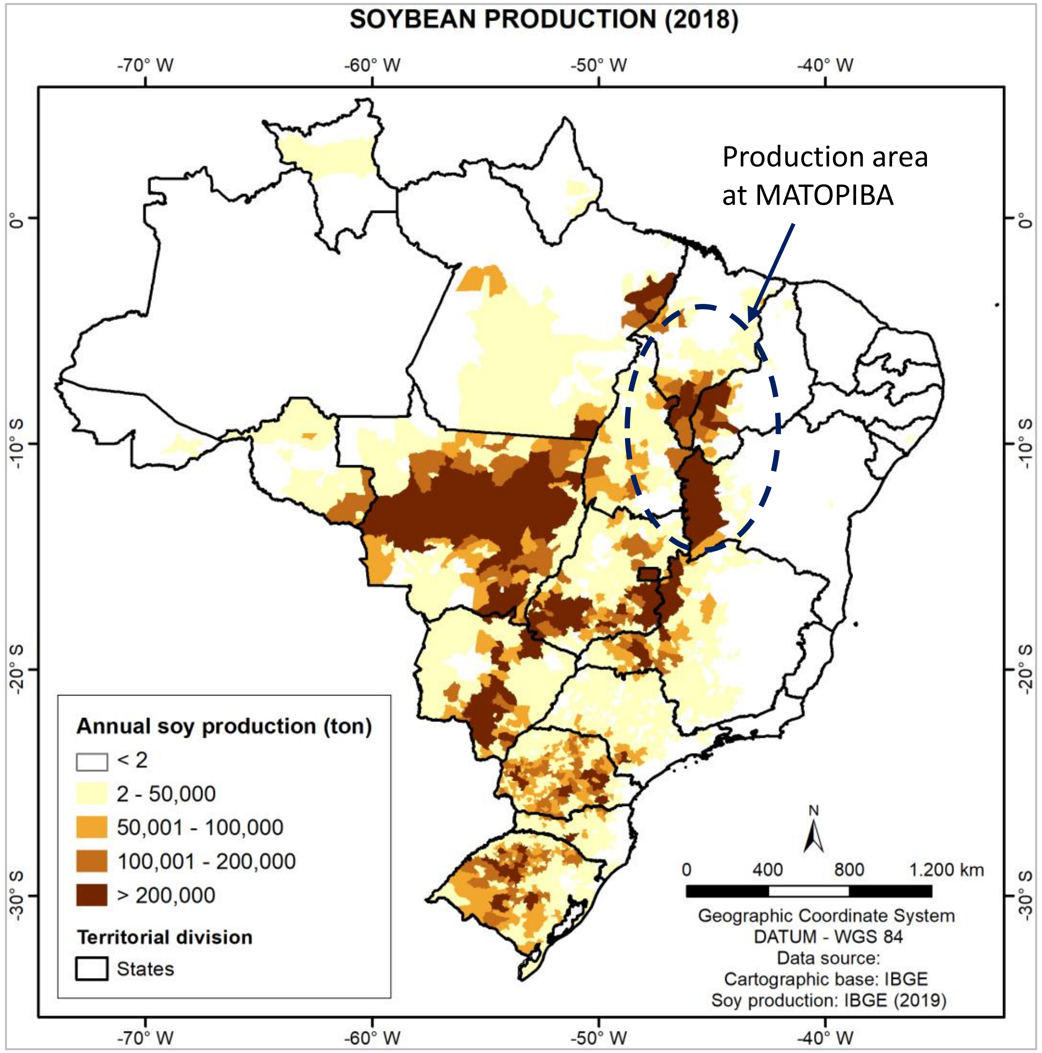
Source: adapted from ICAO (2018) and ASTM (2020)




Source: Wang et al. (2016)

- The route HEFA-SPK is currently commercially available.
- According to Le Freuve (2019), the production cost of bio-jet fuel based on this route was 0.70-1.60 US$/L in 2019 (break-even crude oil price between 110-260 US$ per barrel).

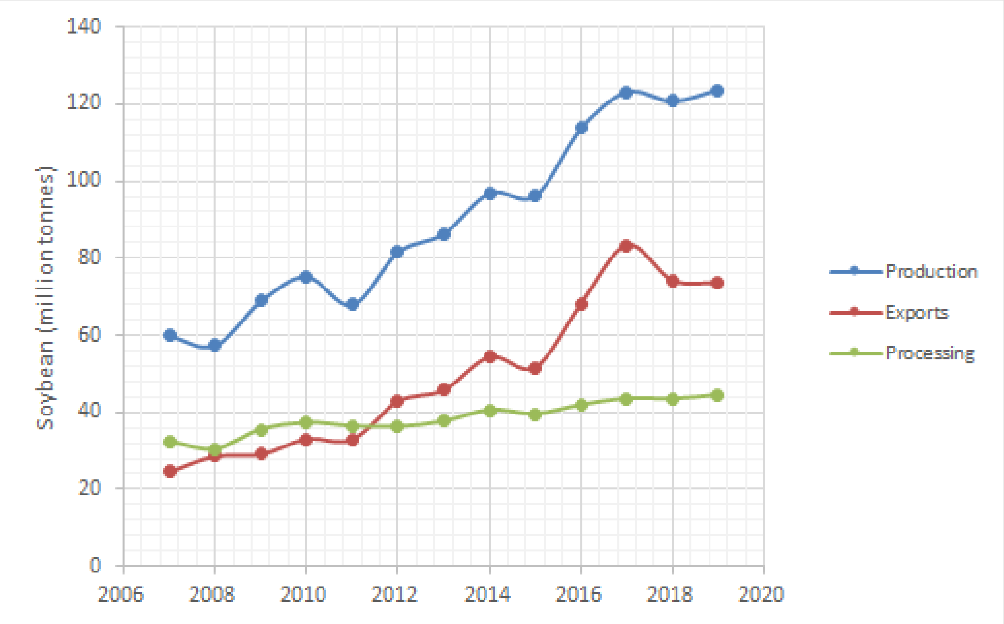
# Soy production in Brazil (1)

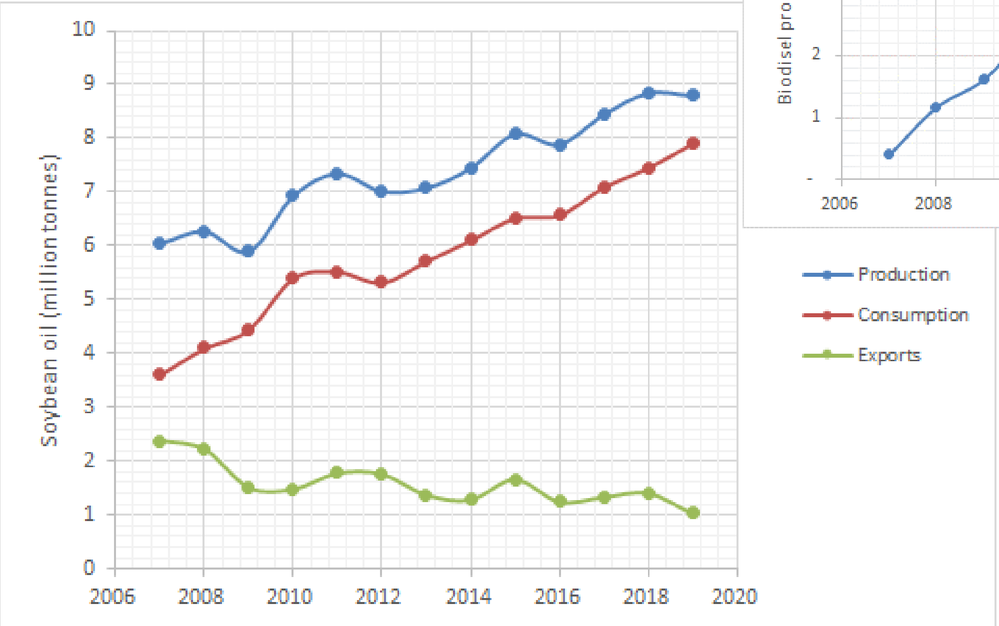


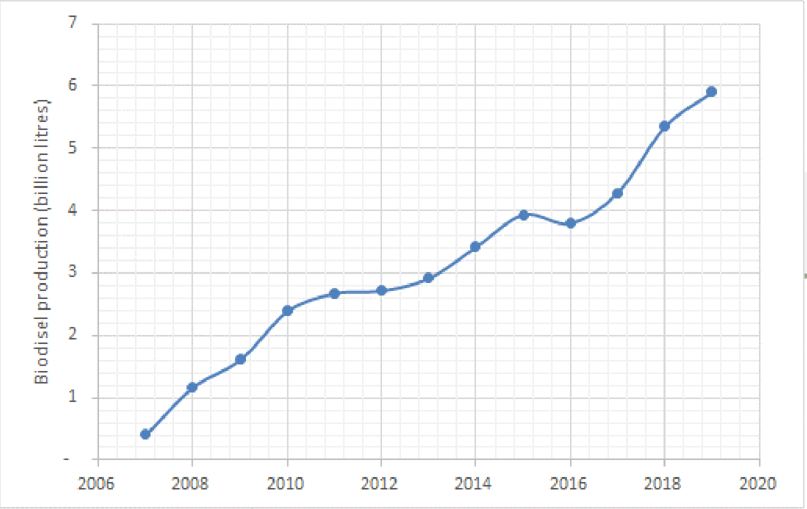

Data source: IBGE (2019) and AGRIANUAL (2020)

- Soy is by far the largest agricultural crop in Brazil. In 2018, the production was over 116 million tonnes. That year the cultivated area was 34.3 million hectares. In 2020, production is expected to be 8-9% higher compared to 2018.
- Worldwide, Brazil is the largest soy producer. Over 60% of grain production is exported as such.
- As for the production of soybean oil, it was about 8.4 million tonnes (on average) in the last three harvest seasons.
- The soy production started in Brazilian South, and moved to the Central region. The new frontier for soybean is the so-called MATOPIBA.

# Soy (and soybean oil) production in Brazil (2)




Data source: ABIOVE (2019), for soybean and soy oil; ANP (2020), for biodiesel production.

- The figures show the evolution of soybean and soybean oil production from 2007 to 2019. It can be seen that soybean processing (i.e. oil extraction) has grown much less than soy production (e.g. 53% of soy produced was processed in 2008, and it was only 36% in 2018). It can also be observed that the domestic consumption of soy oil has grown steadily, mainly due to the growing production of biodiesel (see top-right small figure). In Brazil, the bulk of biodiesel production (75-80%) is from soybean oil.

# Cases studied (1)

- Three cases studies, considering both the current soy production (and soy oil already available) and the expansion of soy cultivation.
- The first study considers the production of bio-jet fuels from the soy oil exported (data from 2018 were used). The oil availability (1.4 million tonnes) would allow a relatively small production (no more than two industrial plants with capacity of producing 2.5 thousand tonnes of hydrocarbons per day) and a relatively high cost (assuming the opportunity cost).
- In this case, the bio-jet fuel 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).

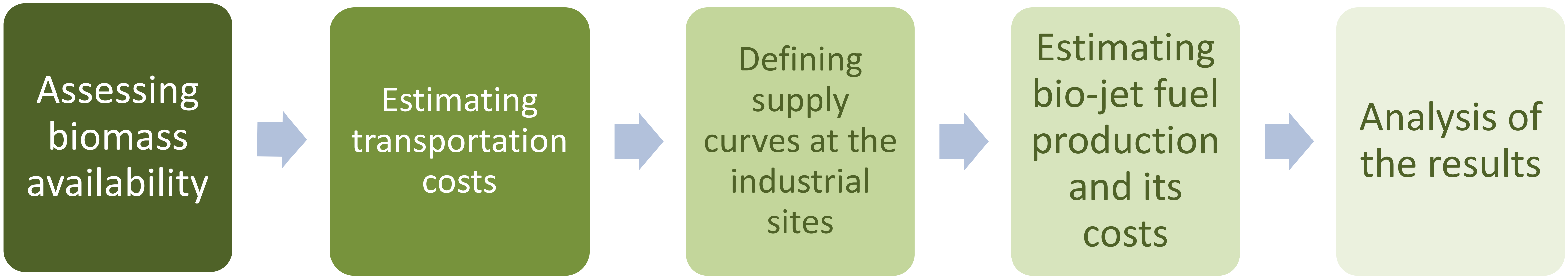
# Cases studied (2)

- The second one considers the production of bio-jet fuels from the existing soy (2018 production), assuming the oil extraction in the processing units not in use in 2018. As for defining oil costs, the study has two variants: (1) the opportunity cost that corresponds to the estimated market price of soybean oil in different locations, and (2) a hypothetical supply chain in which the aim is to reduce the soy oil cost at the refinery site.
- In 2018 there was 22 processing units not in use, corresponding to almost 17% of the total installed capacity (i.e. 7.3 million tonnes of soy.year$^{-1}$) (ABIOVE, 2019). Processing this extra soy would imply reducing grain exports by almost 9%, but enlarging soy oil production by 1.48 million tonnes (about 17% of the soybean oil production in 2018).

# Cases studied (3)

- The third case considers a vertical supply chain: expansion of soybean production and processing in new units, aiming to reduce soybean oil supply costs. These new processing units would be located close to the areas where it would be possible to produce soy at the lowest cost.
- Soy expansion would occur over pasturelands (2018 satellite images were used).
- Soybean meal would be used as feed for confined cattle and, for this reason, places with a high concentration of pastures were sought.
- The soy oil would be transported by trucks from the new processing units to two oil refineries (REVAP and RNEST), where the biofuel plants would be located.
- RNEST is a new oil refinery, located nearby Recife, in Northeast Brazil.

# Methodology: general procedure




Scheme indicating the main activities in the process of evaluating the potential and economic viability of bio-jet fuels, 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

- Existing production
- Market constraints
- Estimating costs (or opportunity costs)

→ **Biomass currently available**

- Biomass suitability
- Areas available and where production is desirable
- Potential yields based on modelling
- Estimated production costs

→ **Biomass available due to expansion**

# 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

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

→

Soy oil supply curves are set for each supply route, considering different bio-jet fuel production capacities

# Methodology … assessing costs and analysis of the results

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

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

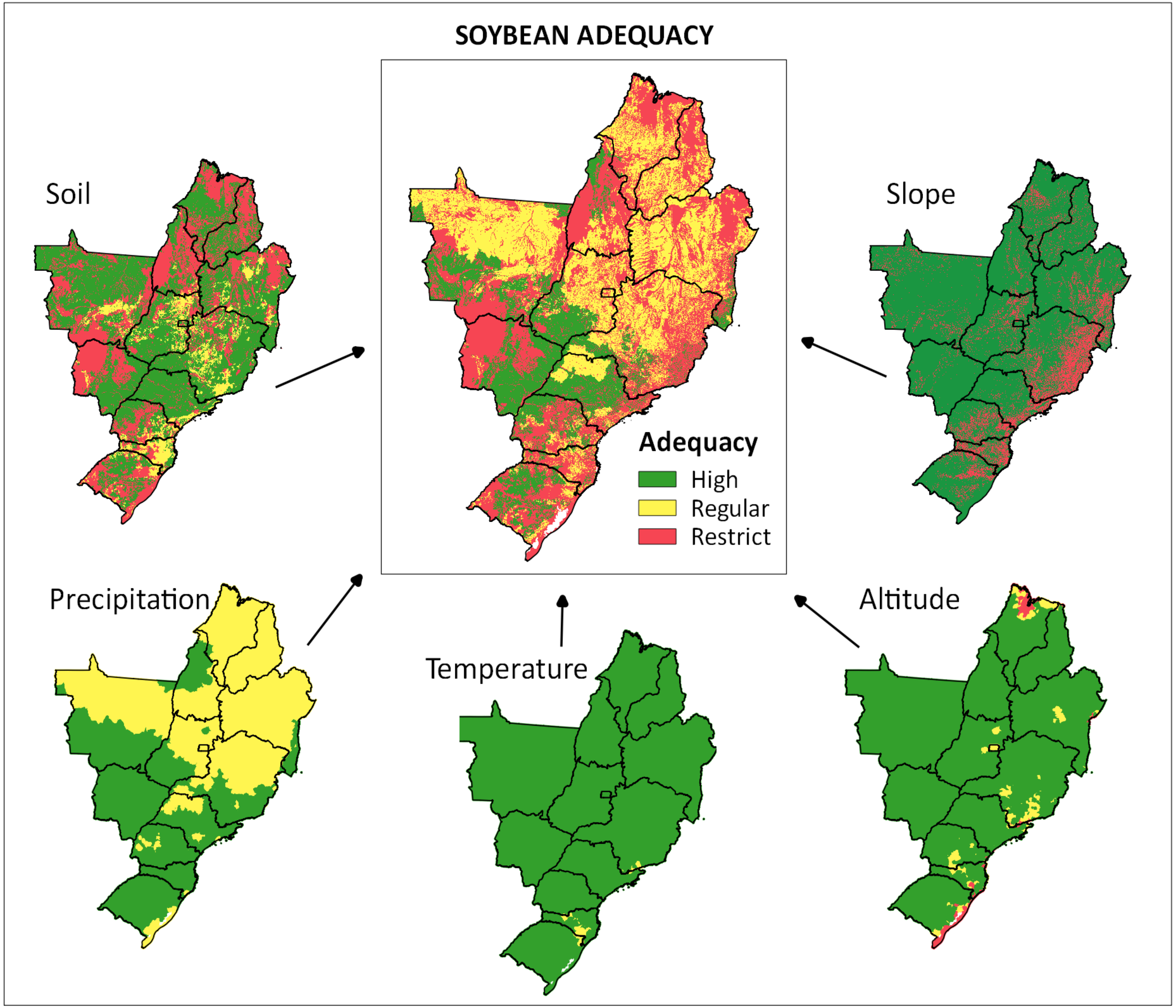
→

Analysis of the results, comparing with those presented in the literature, and actual fossil kerosene prices, considering cost reduction opportunities and trends, etc.

# Soy suitability (1)

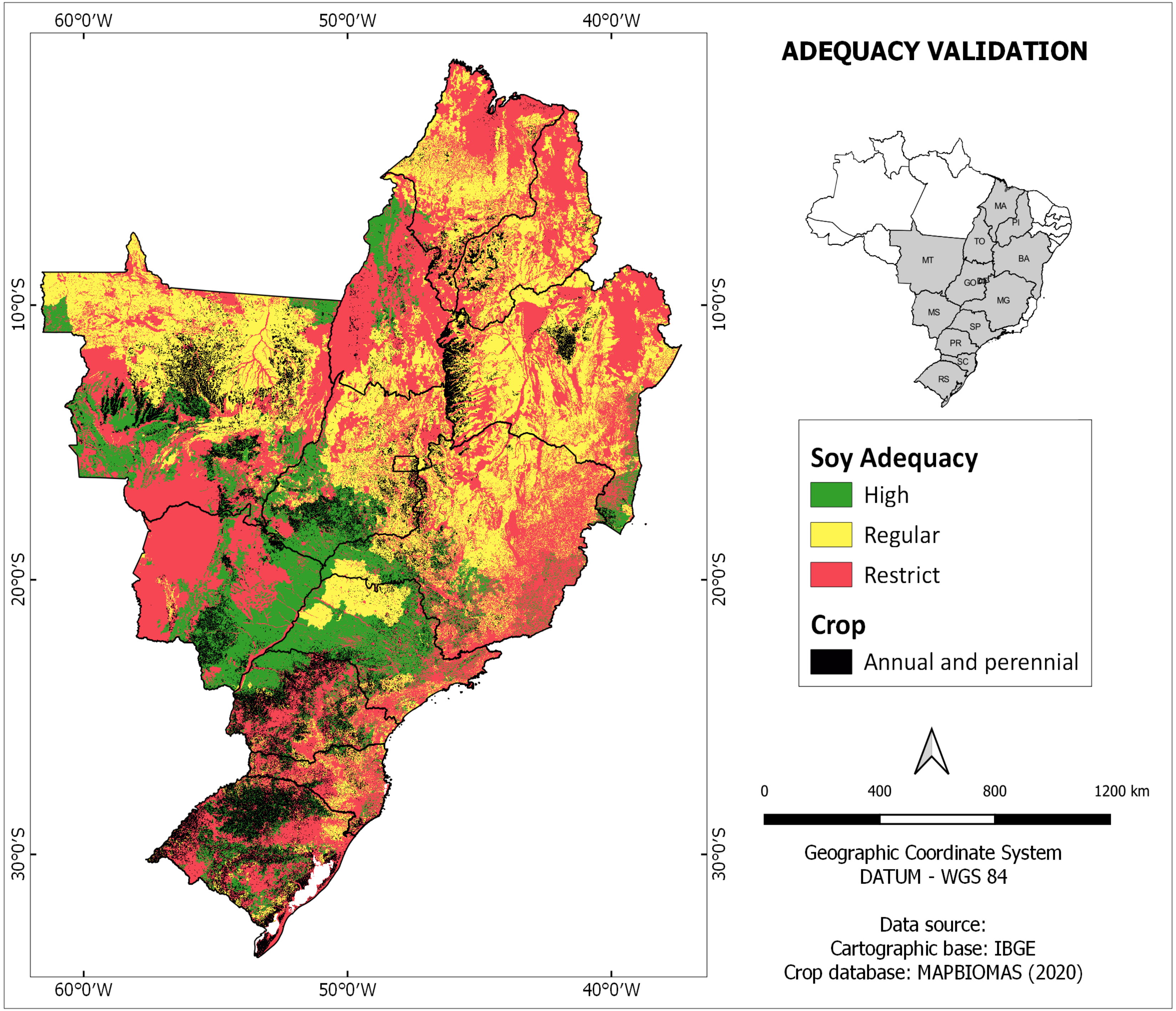
- The climatic suitability was defined according to FAO (2007) (the original procedure was simplified due to data constraints), considering that in Brazil planting is possible from September to January. Rainfall and temperatures were the main parameters considered.
- Altitude (based on the current largest soybean growing areas in Brazil), slope (<13% to allow full mechanization) and soil quality were also parameters used in the procedure.
- All parameters were classified into three groups (e.g. suitable-not suitable; good-bad), except the slope, and the high potential suitability was defined for the condition in which the best classification was achieved for all of them. Not meeting an important condition implies low suitability, but in practice, this does not necessarily mean that production would be impossible.

## Soy suitability (2)

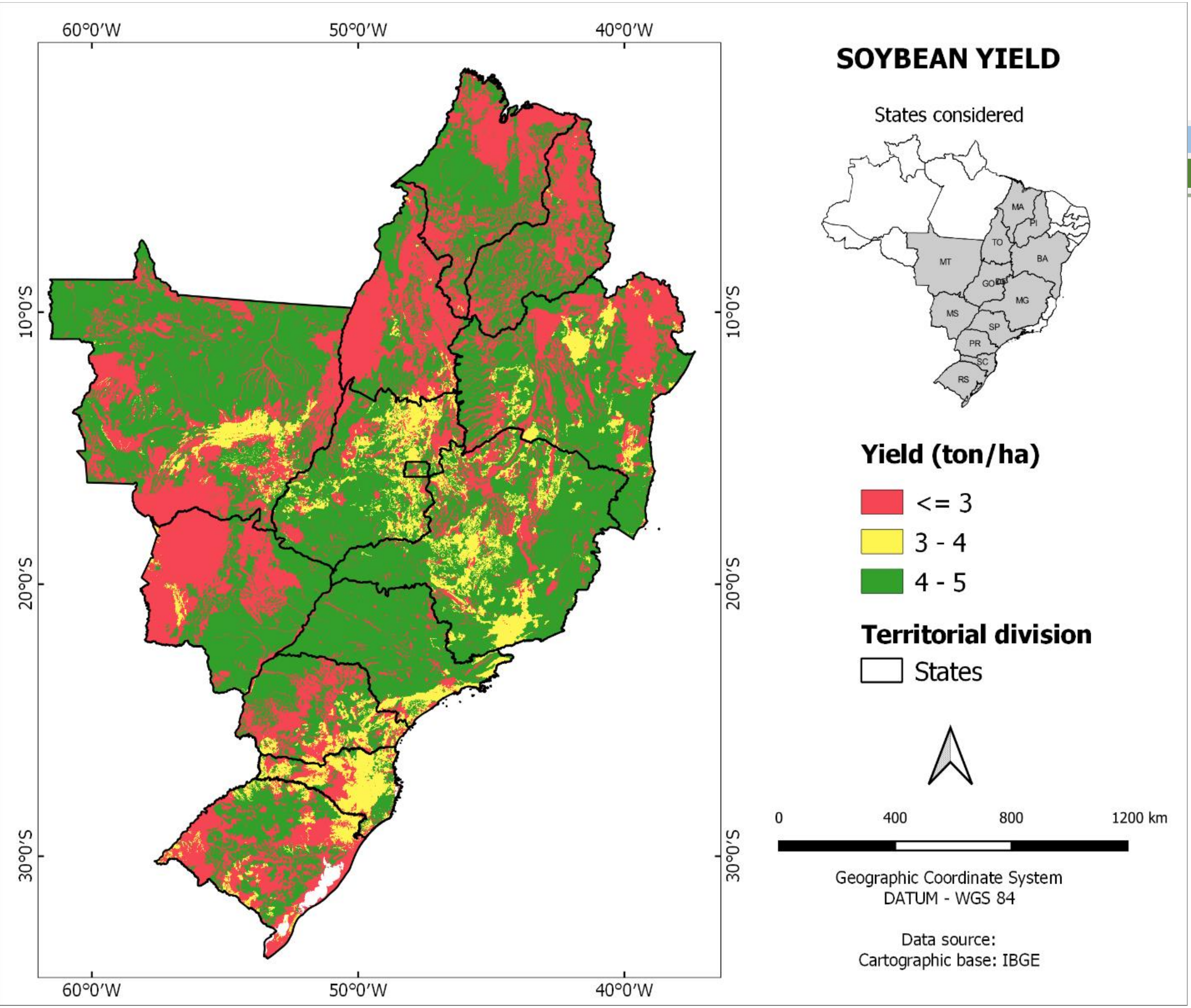



- It can be seen that, under Brazilian conditions, atmospheric temperatures and altitude are less restrictive parameters.
- On the other hand, soil quality imposes the main constraints (see background maps at the platform database).
- Obviously, data resolution, especially in the case of soil, reduces the accuracy of the classification procedure.

# Soy suitability (3)



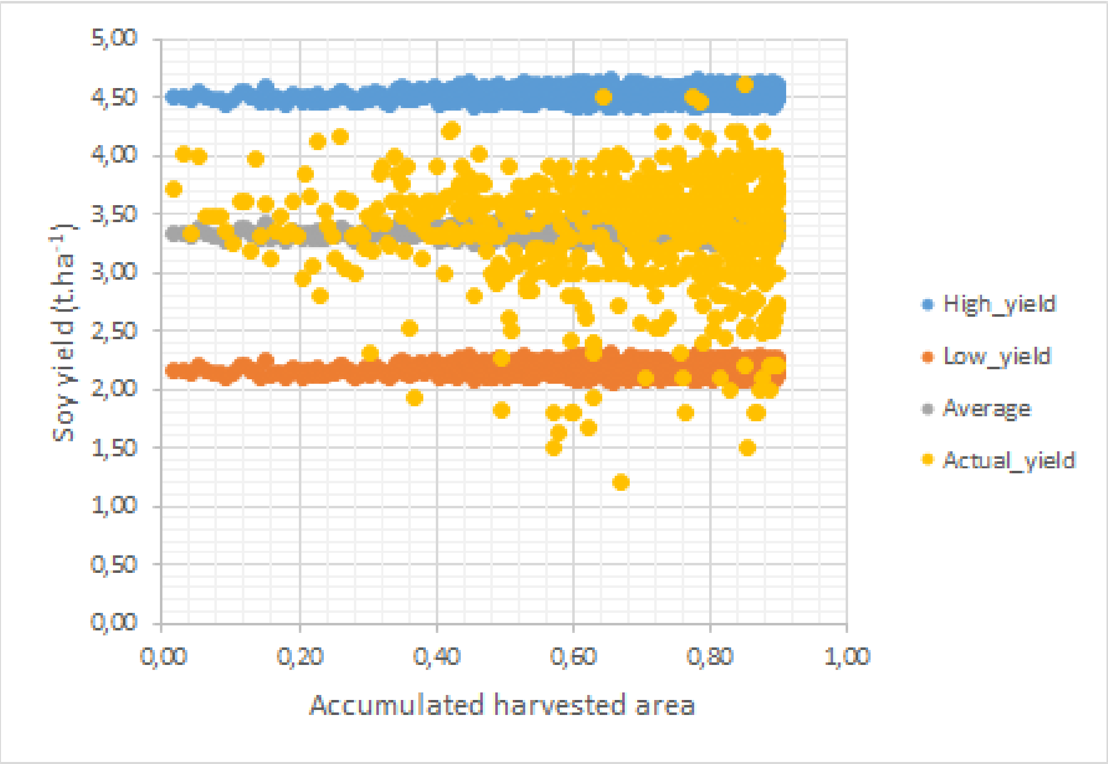

- The map of land use/land cover for 2018 (Mapbiomas, 2020), considering annual and perennial crops, was combined with the suitability map.
- The map of soybean production in 2018 was also used in the validation process.
- It can be seen that there is good match between the estimated suitability and land use/land cover maps.




# Soy productivity (1)

- A statistical function was defined (in municipal basis) between actual (average) yields (t.ha$^{-1}$ in 2018) and a set of explanatory variables (rainfall and air temperature; average, maximum and minimum values over the growth period).
- Dummy variables were introduced into the model in order to differentiate the average yield from the best and the worst cases.
- All explanatory variables are statically significant at least at 90%. The adjusted correlation coefficient is 80%.

# Soy productivity (2)

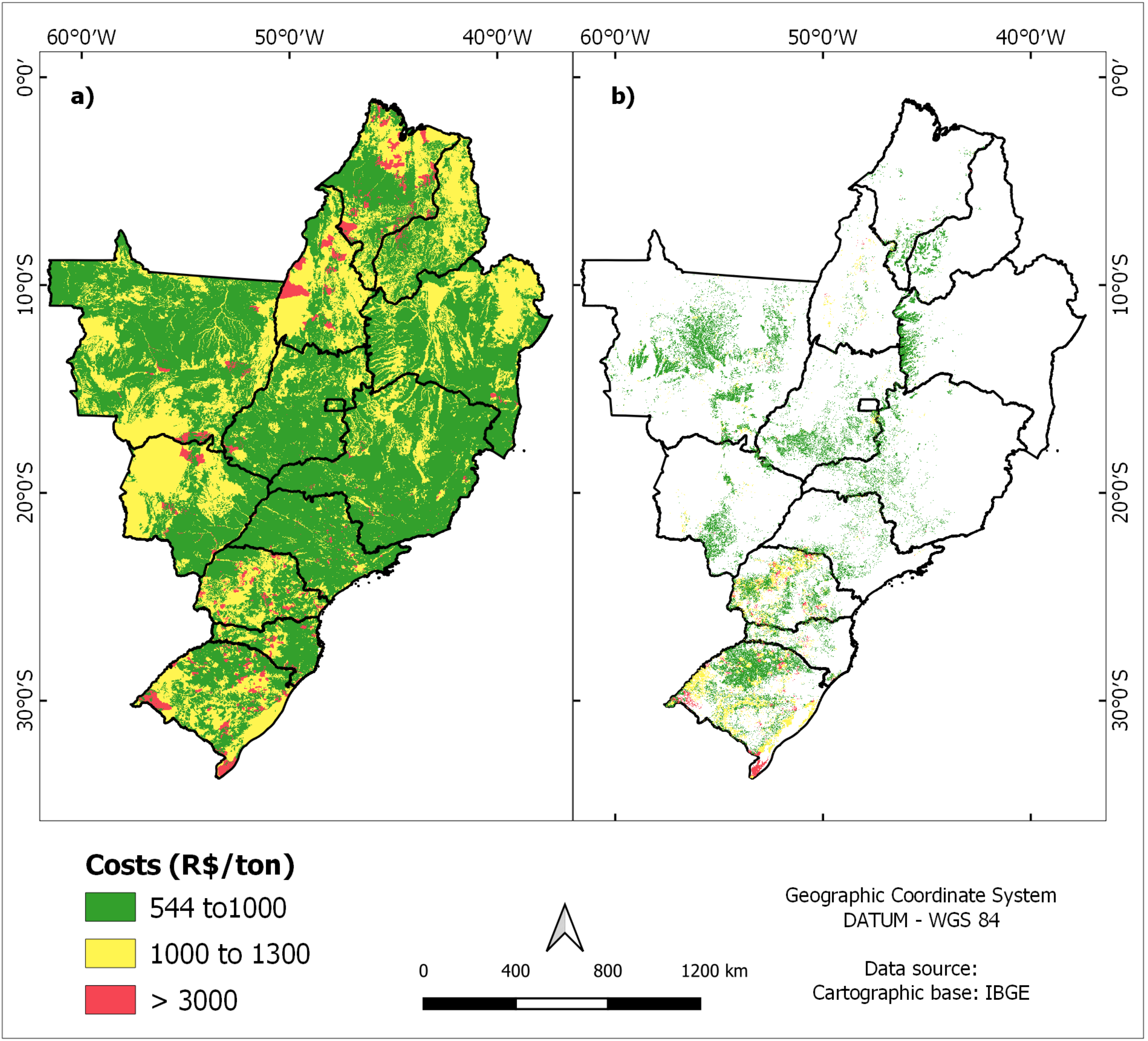



| State | Share (%) | Weighted average | IBGE | Deviation | Agrianual | Deviation |
|---|---|---|---|---|---|---|
| RS | 16.7 | 3.34 | 3.10 | 7.7% | 3.01 | 11.0% |
| SC | 2.1 | 3.41 | 3.47 | -1.7% | 3.40 | 0.4% |
| PR | 14.1 | 3.38 | 3.54 | -4.7% | 3.51 | -3.7 |
| SP | 2.6 | 3.37 | 3.50 | -3.7% | 3.55 | -4.9% |
| MG | 4.4 | 3.41 | 3.60 | -5.4% | 3.68 | -7.3% |
| MS | 7.4 | 3.33 | 3.64 | -8.3% | 3.59 | -7.2% |
| MT | 28.2 | 3.31 | 3.35 | -1.2% | 3.39 | -2.5% |
| GO | 9.9 | 3.37 | 3.46 | -2.6% | 3.48 | -3.1% |
| TO | 2.5 | 3.26 | 2.91 | 12.2% | 3.14 | 4.1% |
| MA | 2.5 | 3.28 | 2.97 | 10.5% | 3.12 | 5.0% |
| PI | 2.0 | 3.29 | 3.47 | -5.3% | 3.57 | -7.9% |
| BA | 4.6 | 3.36 | 3.94 | -14.7% | 3.96 | -15.2% |

- Considering the municipalities (730) that accounted for 90% of the area cultivated with soy in 2018, the model induces underestimation or overestimation in a few cases.
- In general, the results of the model are good to very good, except in two cases: (1) in RS, where real productivity in 2018 was impacted by droughts, and (2) in BA, where real productivity seems to have been impacted by the adoption of best agricultural practices.

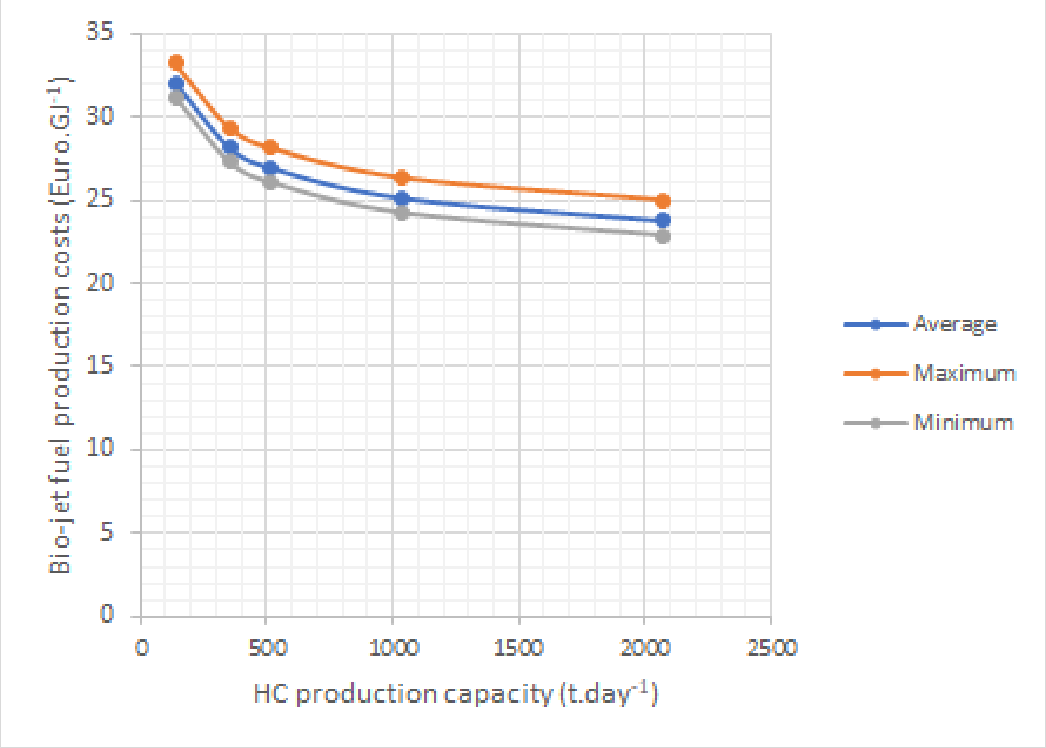
- In the table above the estimated average yields (in more than 4,000 municipalities; weighted by local production in 2018) are compared to the actual average yield (state basis).

# Costs of soy production




- The left figure shows the estimated costs of soy production all over the country.
- Details about the costs estimating procedure are presented in the Supplementary Material.
- The right figure shows the estimated costs of soy production where the production took place in 2018.
- The estimated values were compared to information available (e.g. Agrianual database) and to market prices (e.g. Agrianual and Abiove).

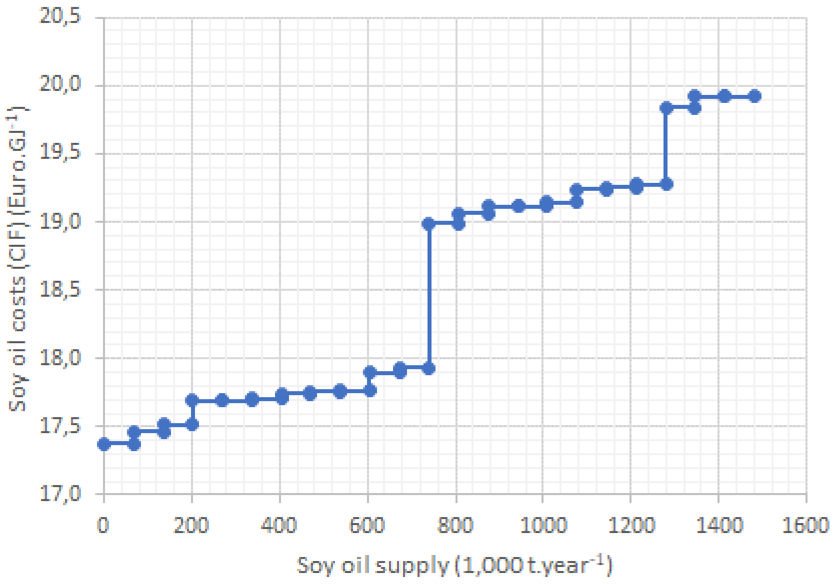
# Results of Case Study 1

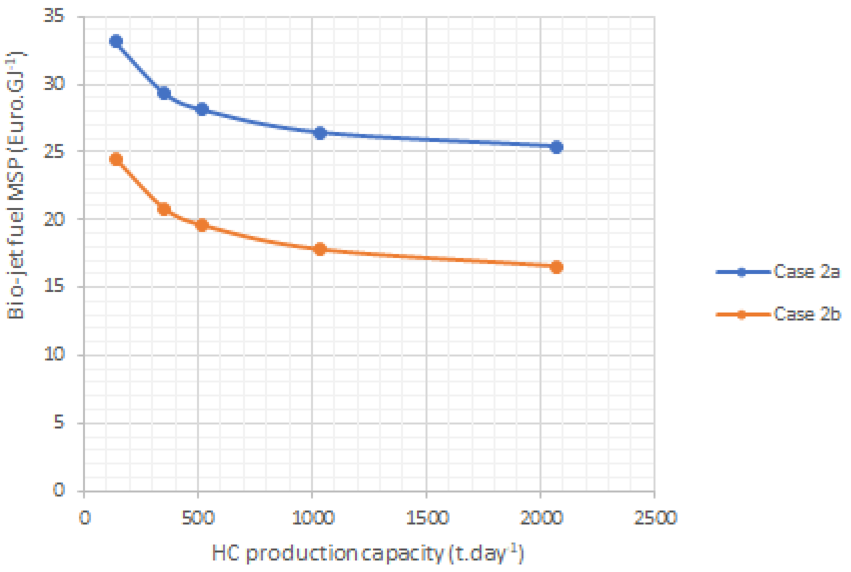



- The opportunity cost of soybean oil corresponds to the international market prices (FOB) in 2018. Average, maximum and minimum annual values were considered (15.53, 16.61 and 14.75 €.$GJ^{-1}$, respectively).

- The estimated bio-jet fuel minimum selling price (MSP) would vary from 24 to 32 €.$GJ^{-1}$ (1,017-1,371 €.$t^{-1}$), considering average soy oil opportunity costs.
- Regarding average figures for each industrial capacity, the MSP variation is ±2.5-5% depending on the oil opportunity cost.
- In the reference study (de Jong et al., 2015), for the same industrial capacity (2,500 t.$day^{-1}$ of hydrocarbons; 300 t.$day^{-1}$ of bio-jet fuels) the estimate MSP is 29 €.$GJ^{-1}$.

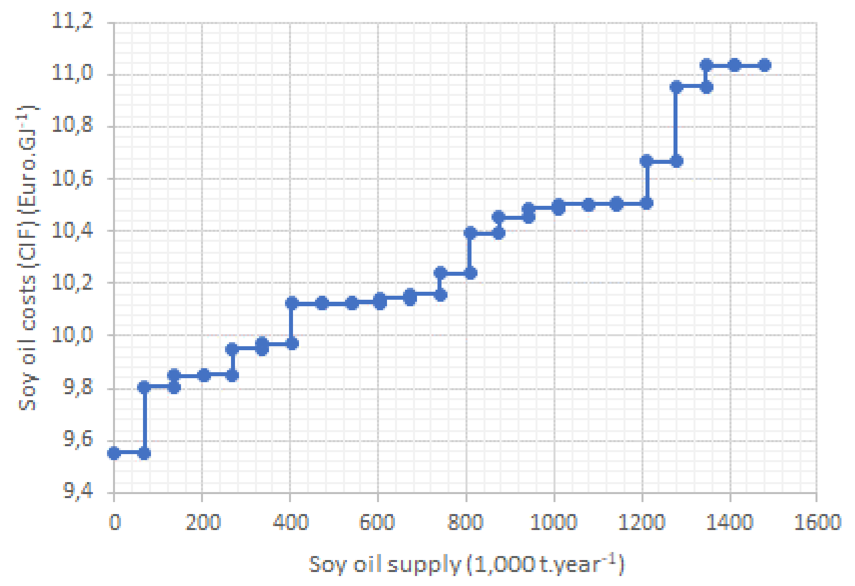
# Results of Cases Study 2a – production at REVAP

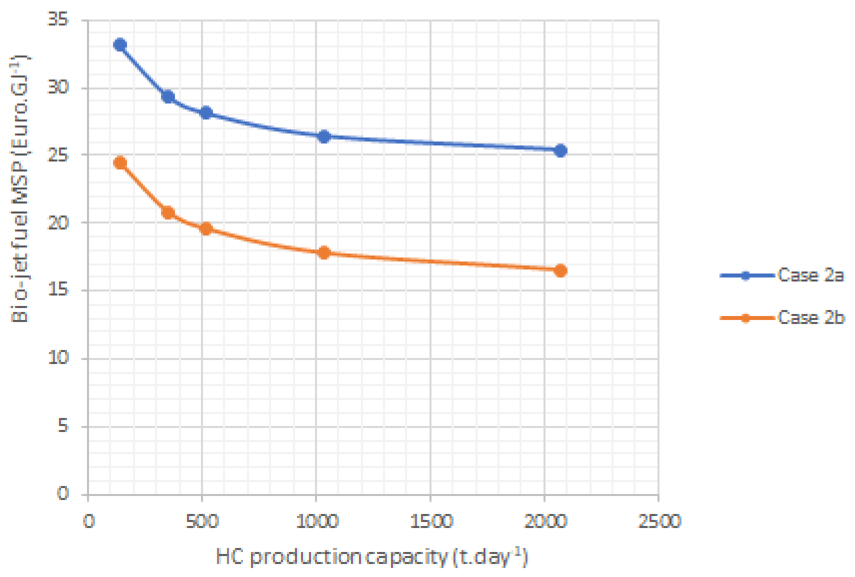



- Case 2a considers additional soy oil production, using the processing units not under operation in 2018. In this case, the soybean oil cost would be the market price that year.
- The estimated bio-jet fuel MSP would vary from 25.4 to 33.1 €.GJ$^{-1}$ (1,086-1,471 €.t$^{-1}$).
- Results are quite similar to case 1.
- The production at a 2,500 t.day$^{-1}$ of hydrocarbons would require 821.3 thousand tonnes of soy oil per year.
- Due to lower soybean prices, the cheapest supply sites would be in the Centre-West region. The impact of transportation costs (of soybean oil) is relatively small.

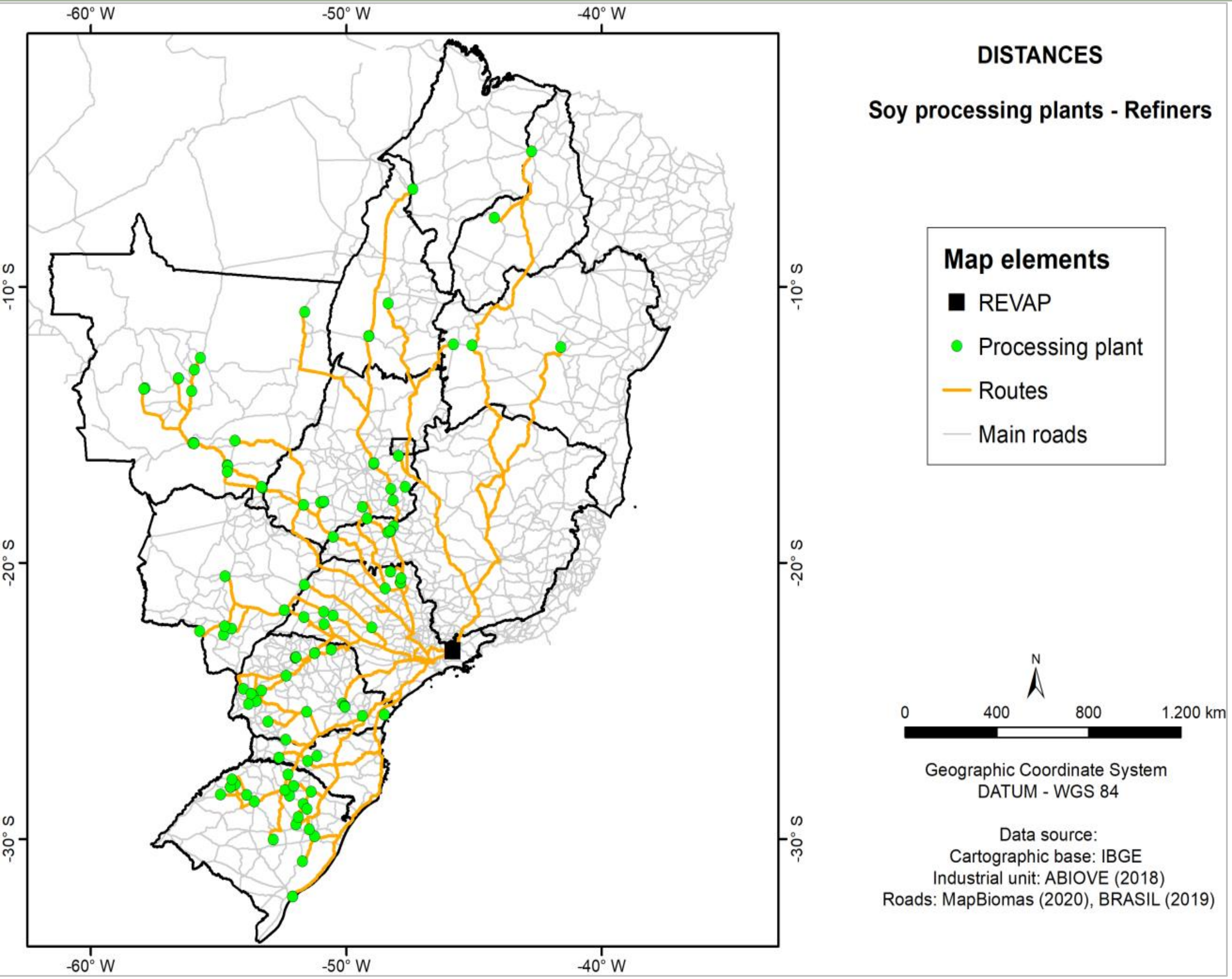
# Results of Cases Study 2b – production at REVAP



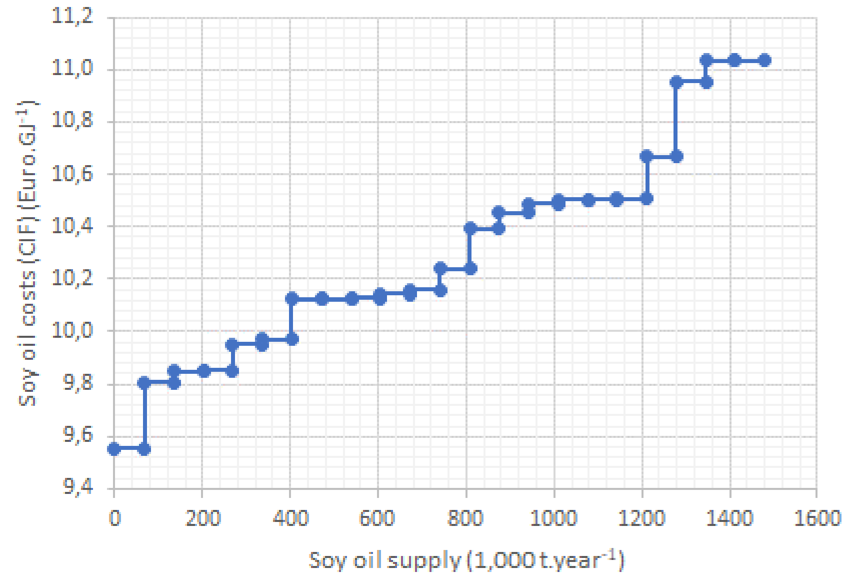

- Equally, case 2b considers additional soy oil production, using the processing units not under operation in 2018. But, here the soybean oil cost is estimated as function of the supply chain costs (i.e. soy price plus the extraction costs), allocating costs by weight between meal and oil.
- The estimated bio-jet fuel MSP would vary from 16.5 to 24.5 €.GJ$^{-1}$ (701-1,049 €.t$^{-1}$).
- The estimated MSP indicates feasibility of bio-jet fuel production at large scale vis-à-vis fossil jet fuel, according to de Jong et al. (2015).
- In case 2a, the impact of the market prices of soybean oil is determinant, and the supply would be mainly from processing units located in Centre-West region. On the other hand, in case 2b the transportation cost of soybean oil is more relevant, and – for large scale production – supply would be also from processing units located in PR and SP.

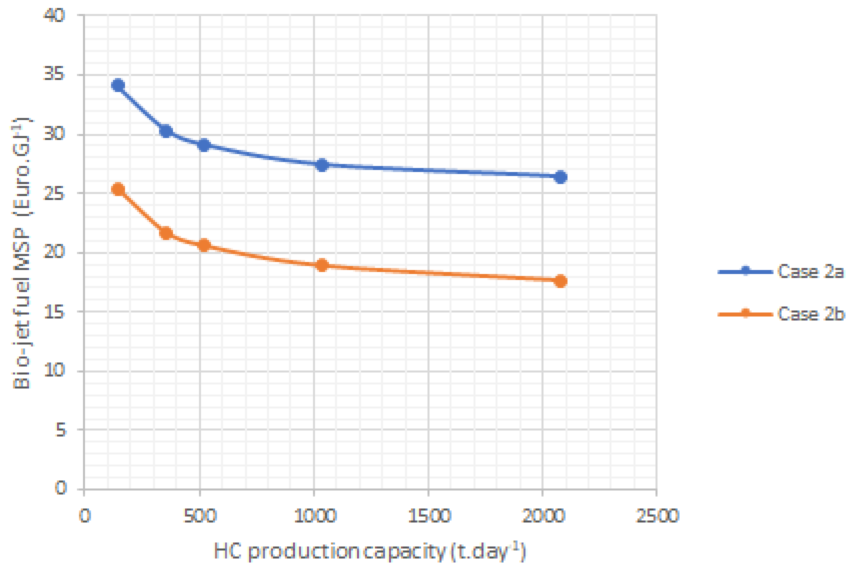
# The routes from soy processing units to REVAP




- In 2018 there was 111 soy processing units in Brazil, being 89 under operation (with different annual capacity factors) and 22 fully stopped.
- The road distance from these processing units to REVAP vary between 451 to 2,677 km (1,190 km on average).

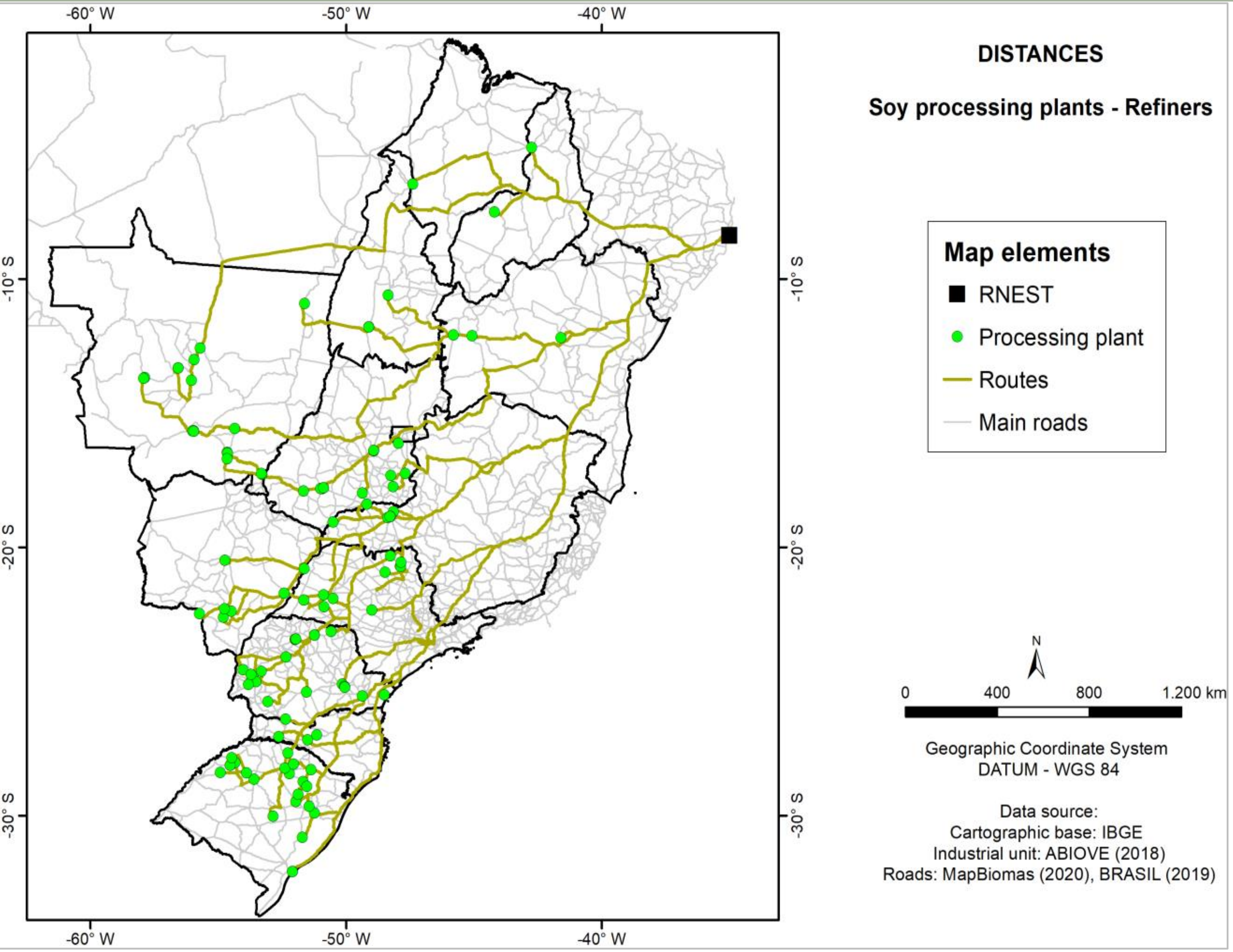
# Results of Cases Study 2b – production at RNEST




- In this case, the assumption is future bio-jet fuel production at RNEST, in Northeast.
- The estimated bio-jet fuel MSP would vary from 17.6 to 25.4 €.GJ$^{-1}$ (755-1,088 €.t$^{-1}$), i.e. the difference is quite small compared to the REVAP case.
- The reason is that the impact of soybean oil transportation is relatively small. Even though, the best supply options would be soy processing units located in Centre-West region and in TO.
- Again, the MSP indicates possible feasibility of bio-jet fuel production at large scale vis-à-vis fossil jet fuel (see analysis of results).

# The routes from soy processing units to RNEST

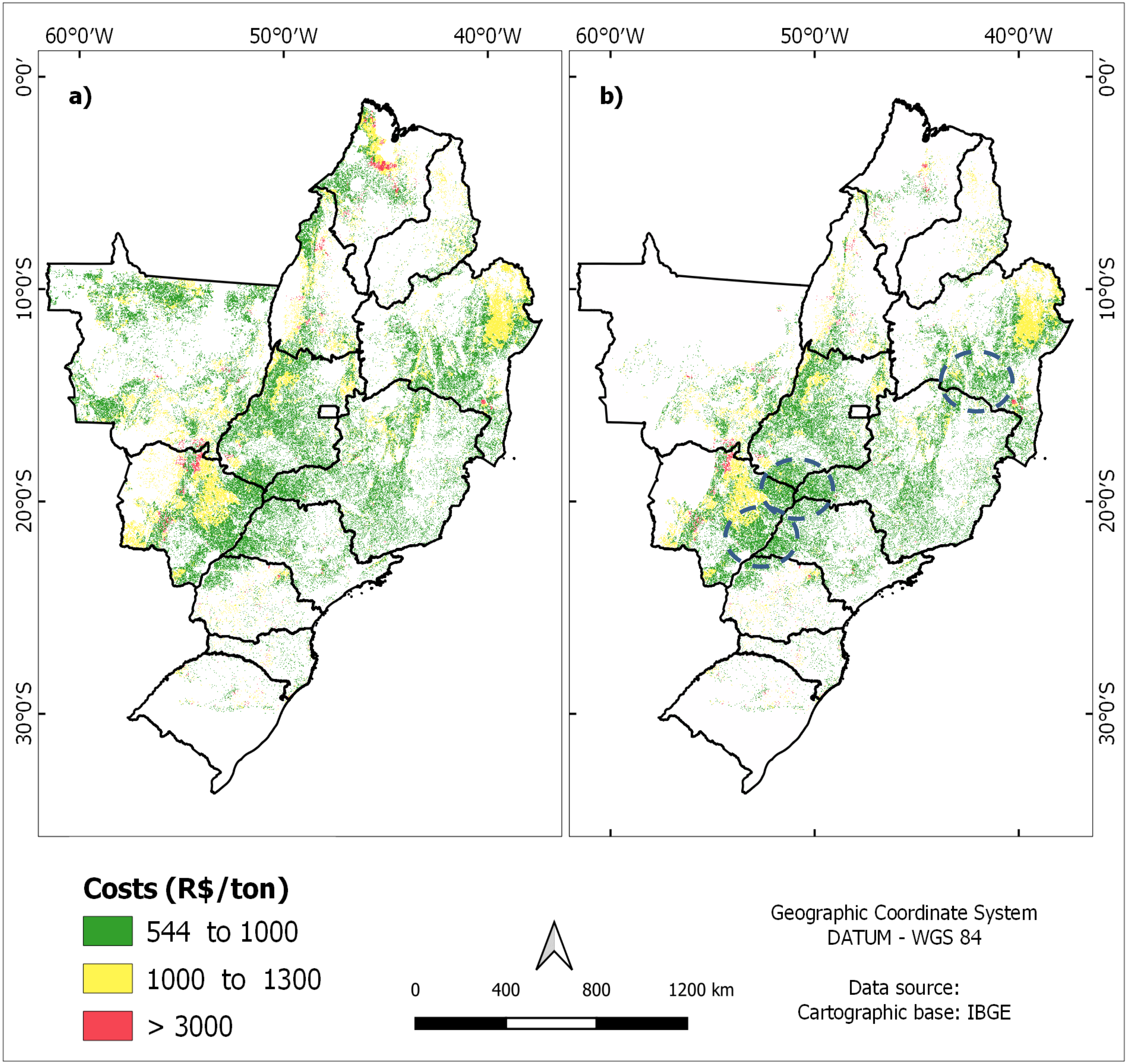



- The road distance from these processing units to RNEST vary between 1,044 and 3,875 km (average 2,953 km).
- The processing capacity of 22 units not operating in 2018 was 7.3 million t.year$^{-1}$, while 62.1 million t.year$^{-1}$ was the capacity of those under operation (the average annual capacity factor was 70%).
- The bulk of the installed capacity (90% of all processing units) correspond to units with capacity lower than 1 million t.year$^{-1}$ of soy.

# Cases Study 3 – Overview

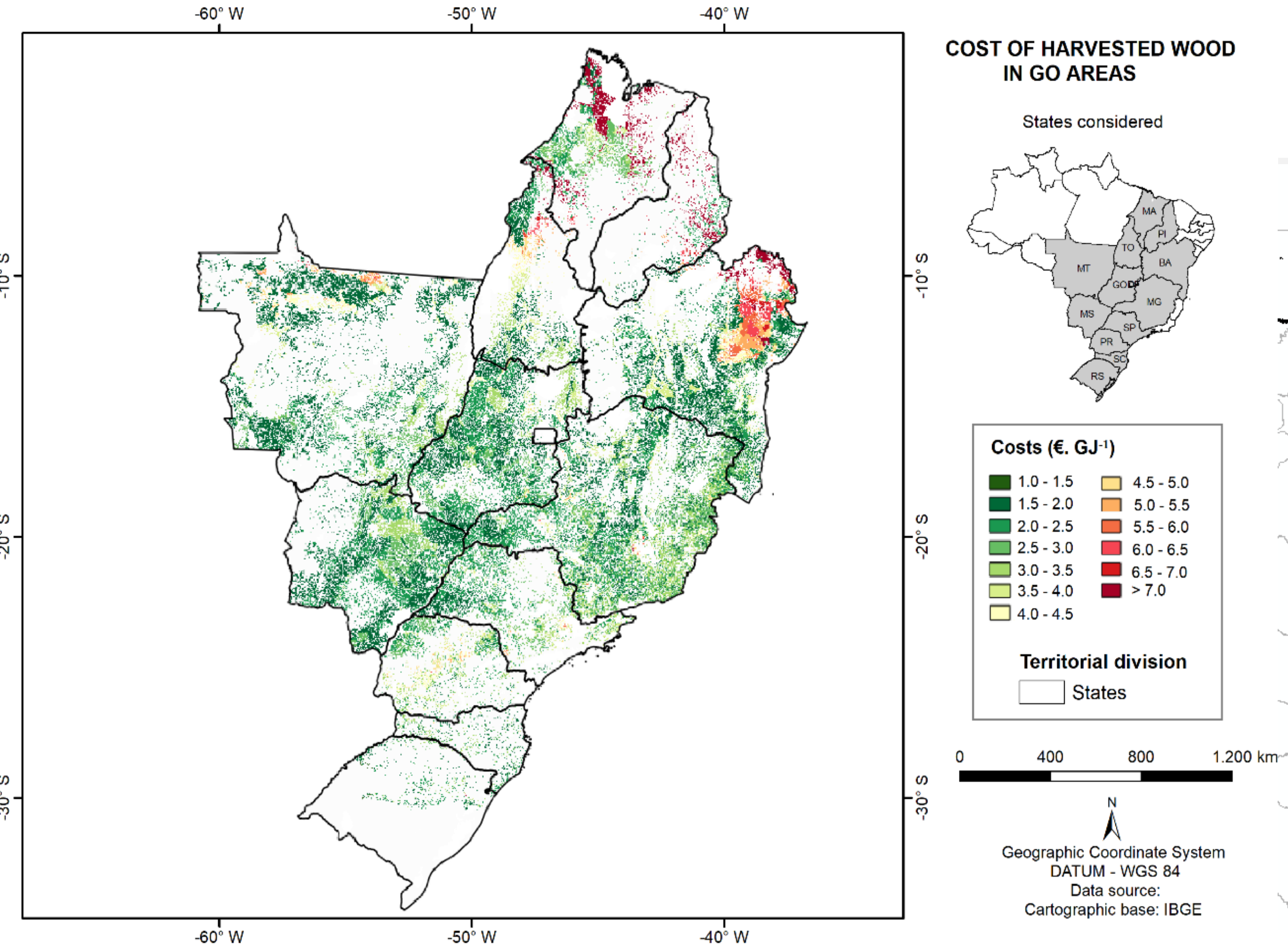
- The rationale is that economic agents, interested in bio-jet fuel production, would develop a vertical supply chain: 1) soybean production would expand over pasturelands, in regions where costs would be lower; 2) soybean would be processed in new units, located close to the production areas; 3) the meal would be sold and it was considered that it could be consumed as feed in intensive livestock; 4) the cost of soybean oil is estimated using a cost allocation procedure, based on weight; 5) soy oil would be transported by trucks from the processing units to REVAP and/or RNEST.
- Three new processing units were considered, located in Brumado (BA), Paranaíba (MS) and Presidente Venceslau (SP). The municipalities were chosen considering 1) where soy production costs would be lower, 2) the proximity to extensive livestock (in 2018), 3) the existence of good pavemented roads, 4) the infrastructure available (in 2018), both from health and education point of views, 5) the proximity to where eucalyptus could be produced at low cost (wood – has been used as fuel in many processing units).
- Simplifying the procedure it was assumed that only one processing unit would be needed in each municipality, but in reality, it should be considered that to supply soybean oil to the largest industrial plants, the best solution would be to have two large processing plants, and these would not necessarily be in the same municipality.

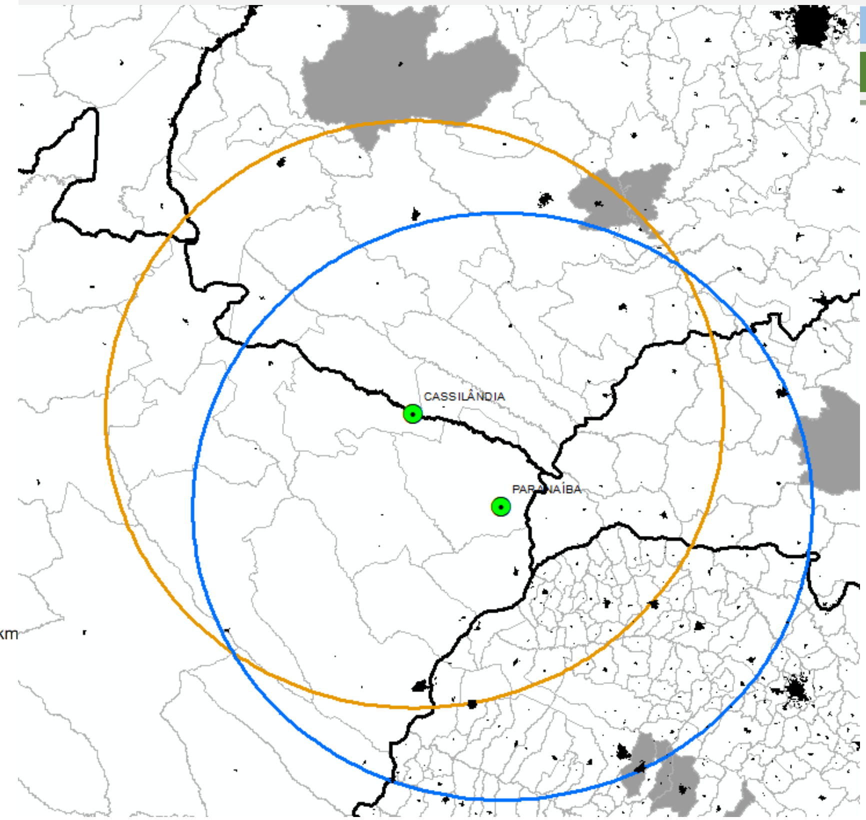
# Costs of soy production (expansion)



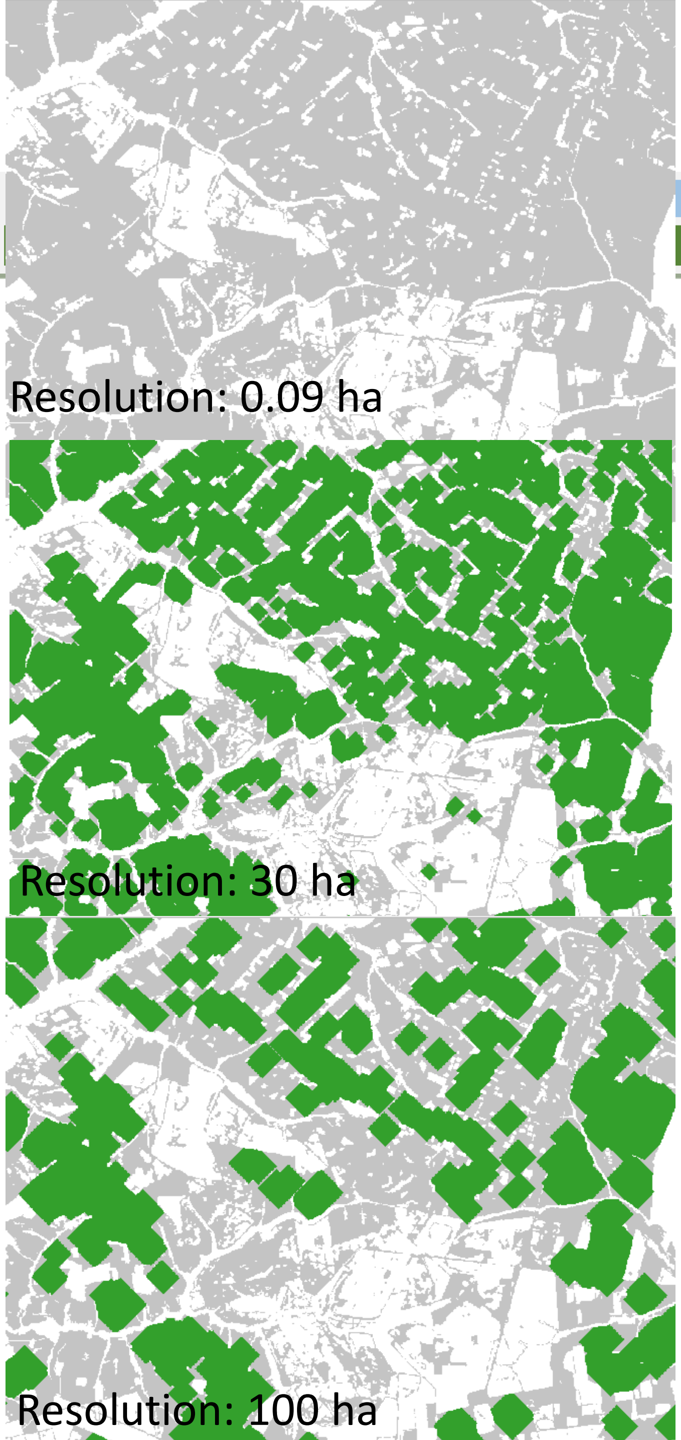

- The figures show the estimated costs of soy production (in new areas), considering that it would occur displacing livestock.
- Case 3 was developed considering sensitive areas that correspond to figure b) (see Supplementary Material; slides “sensitive areas”).
- The circles indicate the areas that have been targeted for the location of the new soy processing units.
- It was assumed that soybean production would be mainly in an area within a 200 km radius circle around the processing plants.

# Additional aspects considered



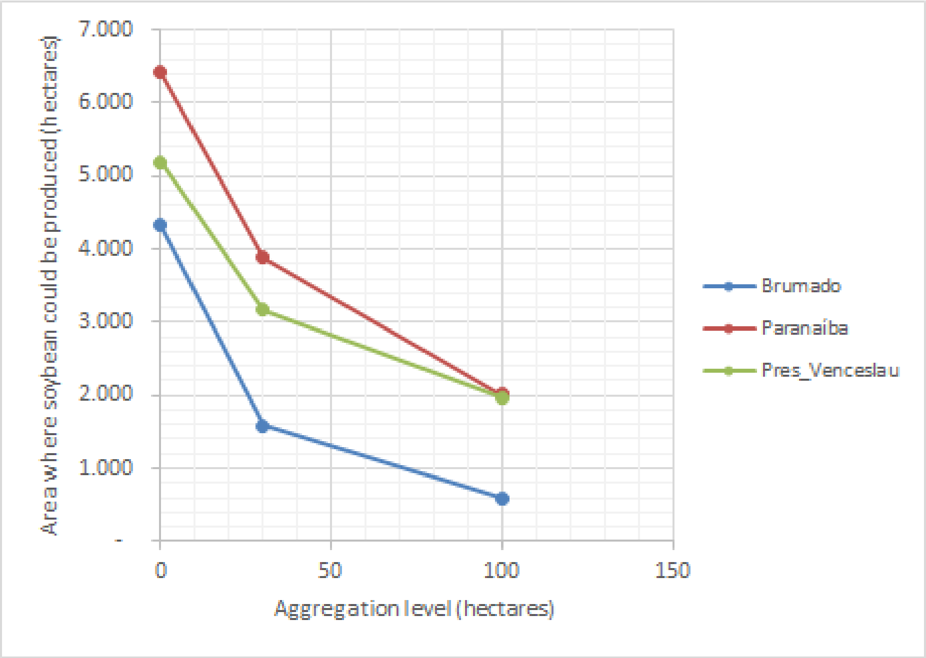




- Figures above illustrate additional aspects considered in the procedure of defining the location of new processing units.
- Figure on the left side shows the estimated costs of harvest wood (eucalyptus).
- The figure on the right side indicates the circles around possible locations, in an effort to identify areas where violations to land use and water use rights have been reported. To be conservative in assessing the potential, these areas were excluded for estimating the potential for soy production.




# Case Studies 3 – estimating soybean potential (1)

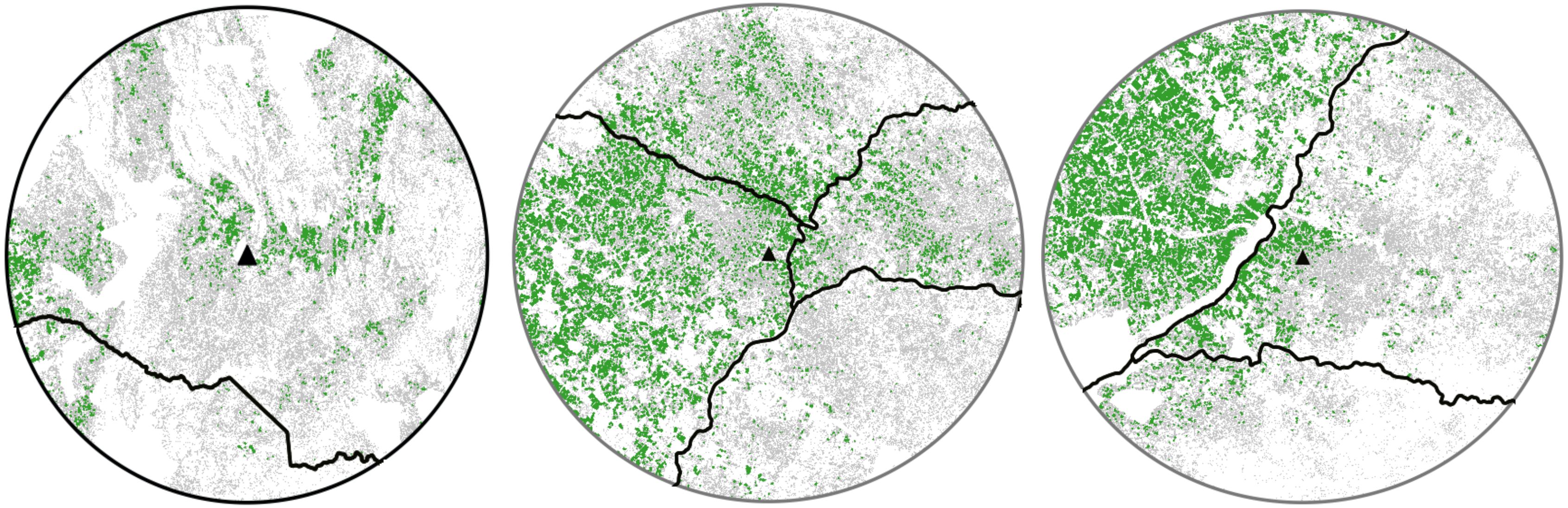
- In the 200 km radius circle around the processing units, potential soybean production at low cost was quantified. The cost of soy at the processing unit was estimated (i.e. the cost of producing soy plus the cost of transporting grains to the processing units).
- To have a more realistic estimate, since soy production is highly mechanized, the pixels were filtered in order to identify clusters with at least 100 hectares of contiguous areas capable of producing at low cost.
- Here, the case of Presidente Venceslau is used as example. Grey areas indicate where it would be possible to produce soy, in go areas, with cost lower than 1,000 R\$.t$^{-1}$. Green areas correspond to the solution after filtering to 30 hectares (intermediate) and 100 hectares (bottom figure).

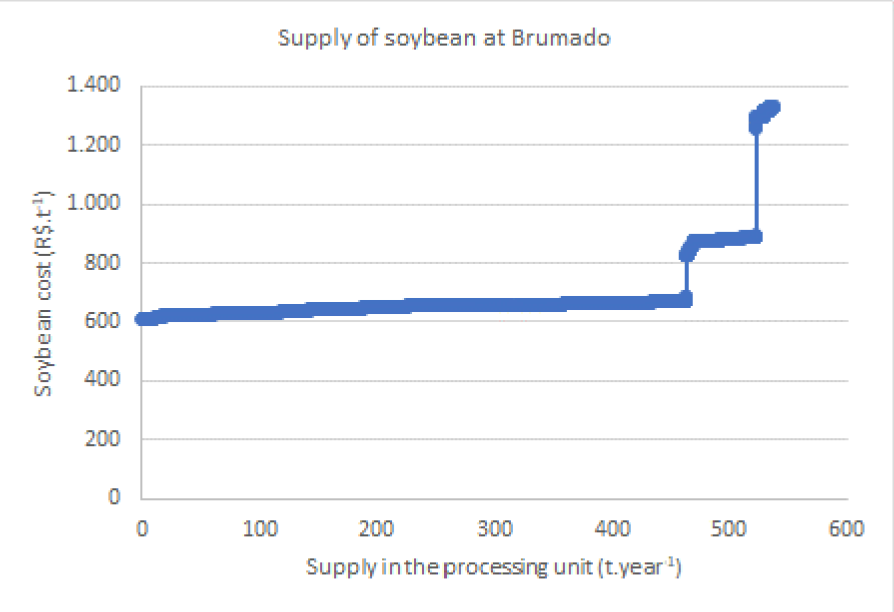


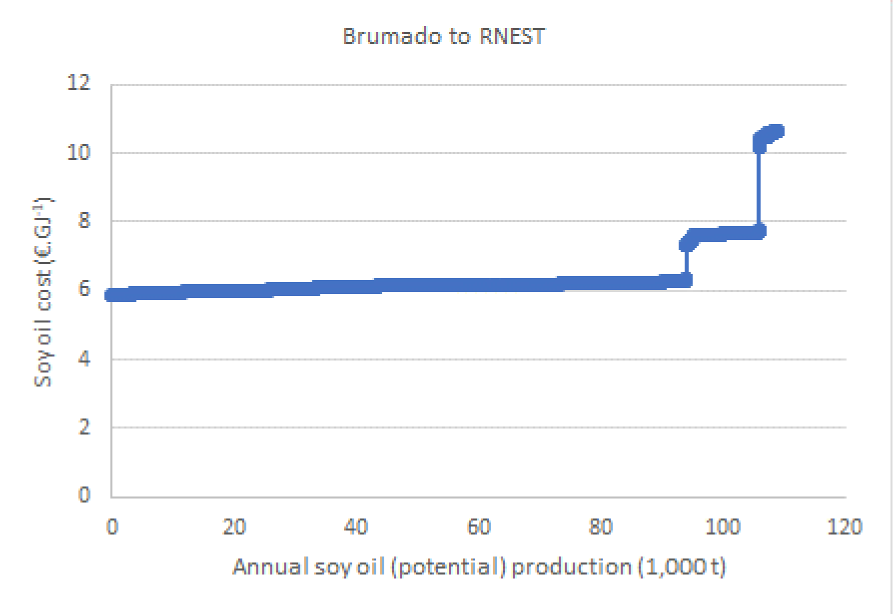

## Case Studies 3 – estimating soybean potential (2)

- As mentioned, in the 200 km radius circle around the processing units, potential soybean production at low cost was quantified. Comparing to soy production costs, as transportation costs are less significant, in practice soybean can be transported from far more distant locations.
- From left to right: Brumado (BA), Paranaíba (MS) and Presidente Venceslau (SP). Green areas indicates the final solution (after filtering up to 100 hectares, at least).

- The impact of filtering would be deeper in Brumado, with an area reduction to 14%. In case of Presidente Venceslau the reduction would be to 38% (32% in case of Paranaíba).
- In the circles, the triangles indicate the location of the processing units.



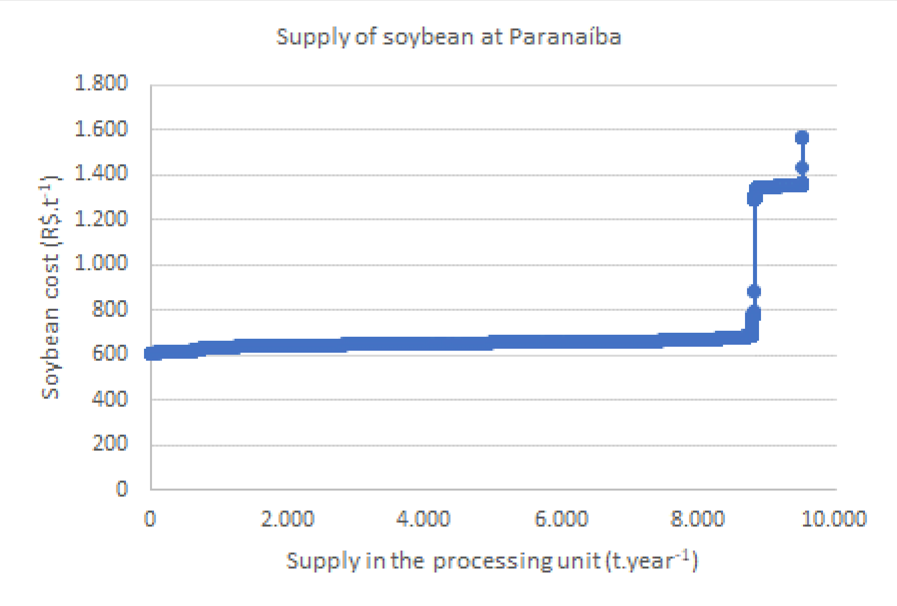


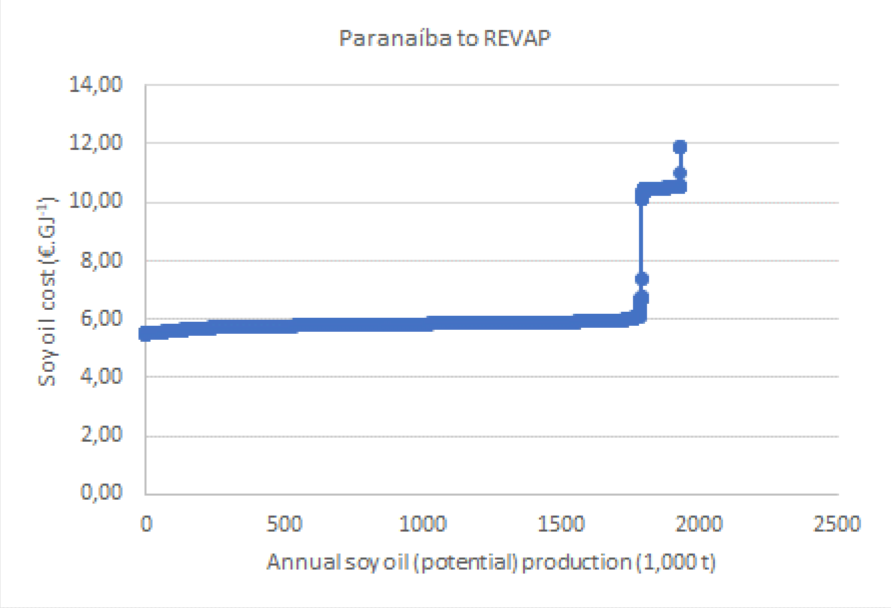




# Case Study 3 – Brumado

- In case of Brumado (i.e. production inside a circle with radius 200 km), after filtering for areas larger than 100 hectares, the estimated soy production would be 538 thousand tonnes per year, with an average cost 783 R$.t$^{-1}$ (at the processing plant site; standard deviation 216 R$.t$^{-1}$); the average yield would be 3.9 t.ha$^{-1}$ (a good estimate compared with the references).
- The maximum soybean oil production in Brumado would be 113 thousand t.year$^{-1}$, which is a relatively small amount taken into account the requirement of larger industrial capacities (of bio-jet fuel production) considered in this study. The average oil costs at RNEST would be 7 €.GJ$^{-1}$ (standard deviation 1.44 €.GJ$^{-1}$).

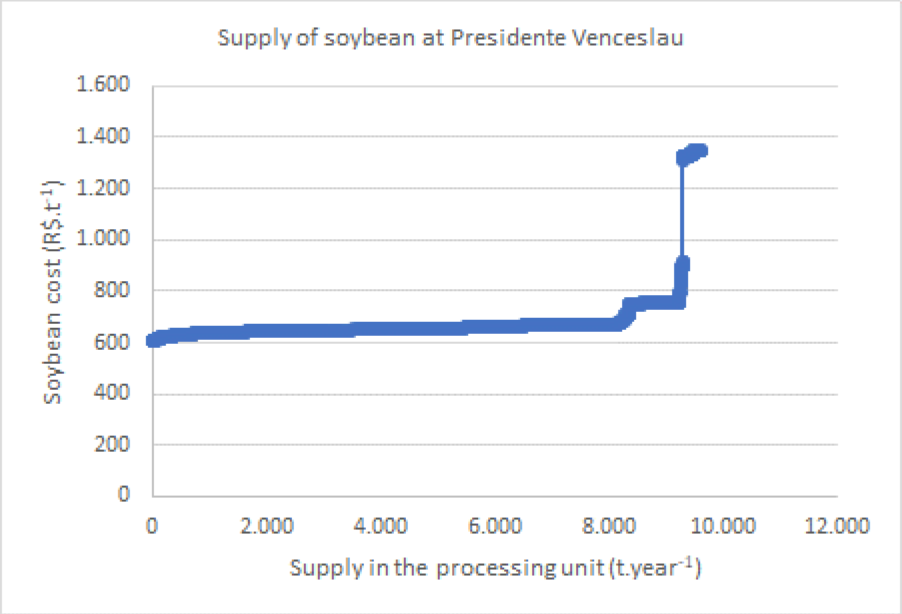
# Case Study 3 – Paranaíba

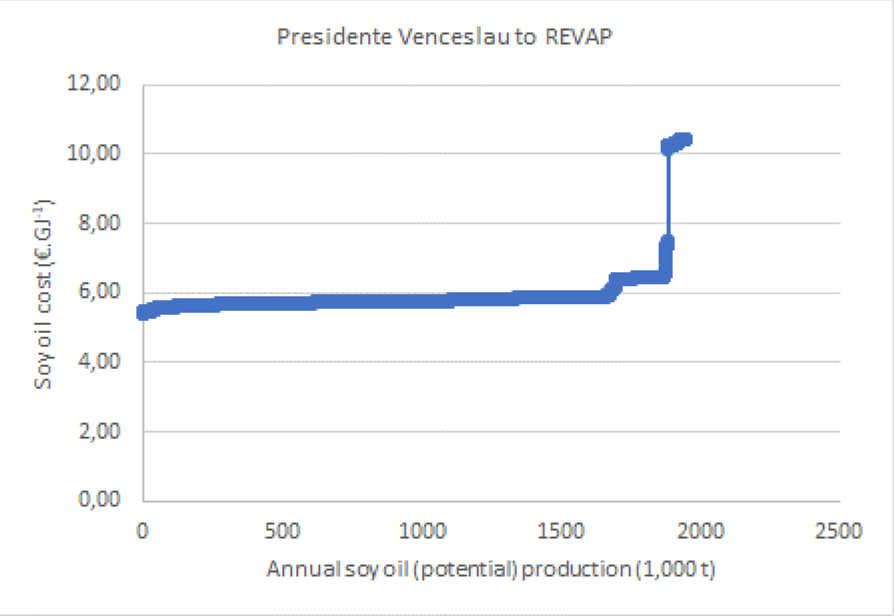



- Around Paranaíba the estimated soy production would be 9.5 million tonnes per year, with an average cost 913 R$.t$^{-1}$ (at the processing plant site; standard deviation 330 R$.t$^{-1}$); the average yield would be 3.7 t.ha$^{-1}$ (again, a good estimate compared with the references).
- The maximum soybean oil production in Paranaíba would be 1.9 million t.year$^{-1}$, which is more than enough to supply the largest industrial capacities considered in this study.
- The average oil costs at REVAP would be 7.56 €.GJ$^{-1}$ (standard deviation 2.21 €.GJ$^{-1}$). This figure would be 8.78 €.GJ$^{-1}$ (standard deviation 2.21 €.GJ$^{-1}$) in case of supplying the industrial unit at RNEST.

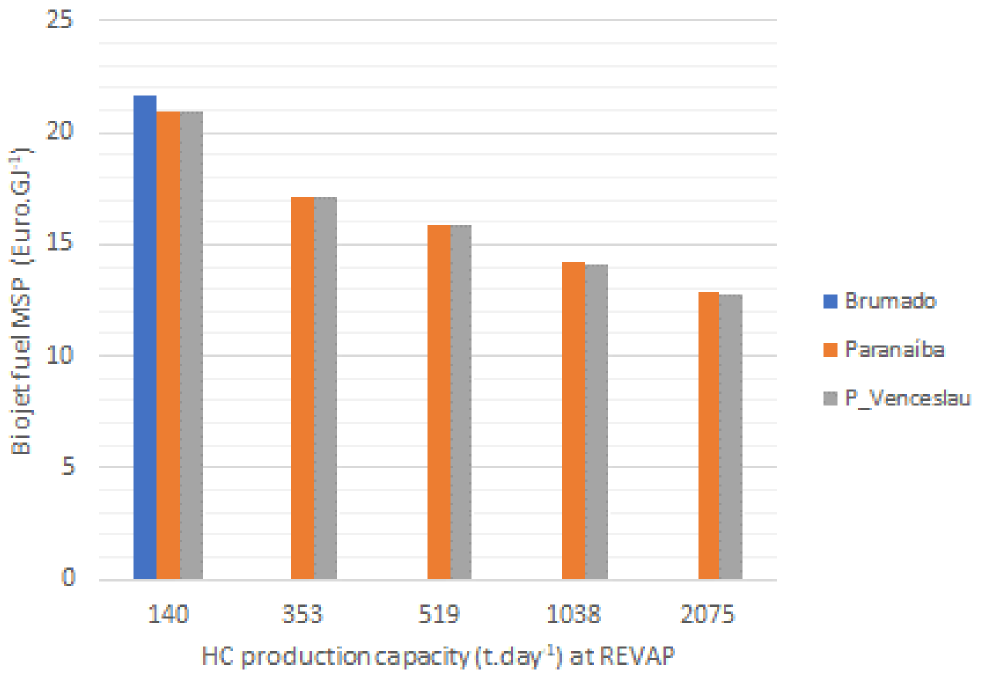
# Case Study 3 – Presidente Venceslau




- In case of Presidente Venceslau, the results show that it would be possible to produce 9.7 million tonnes of soy per year, with an average cost of 891 R$.$t^{-1}$ (at the processing plant site; standard deviation 505 R$.$t^{-1}$); the average yield would be 3.8 $t.ha^{-1}$ (a good estimate for the region around the processing plant).
- The maximum soybean oil production in Presidente Venceslau would be 1.95 million $t.year^{-1}$, which is more than enough to assure the supply of the largest industrial capacities (of bio-jet fuel production) considered in this study. The average oil costs at REVAP would be 7.1 €.$GJ^{-1}$ (standard deviation 2.0 €.$GJ^{-1}$).

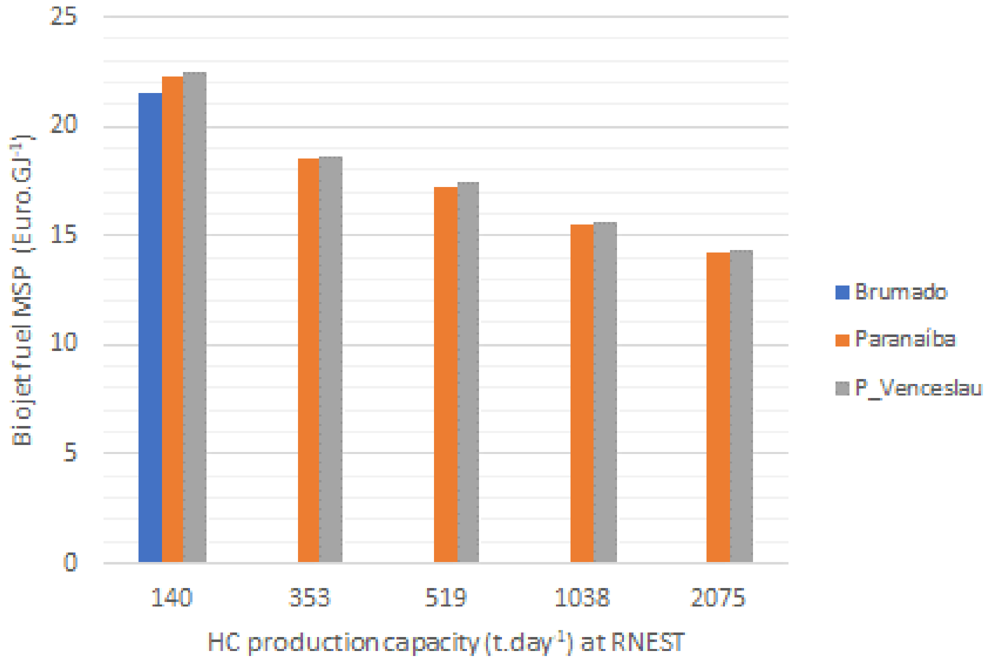
# Case Study 3 – Results for REVAP




- Considering the oil supply from Paranaíba and Presidente Venceslau, the MSP vary from 13 to 21 €.GJ$^{-1}$ (547 to 897 €.t$^{-1}$). Thus, it is possible to conclude that the production of bio-jet fuels could be feasible compared to fossil jet fuels.
- From an economic point of view, the supply from these two sites is indistinctive.

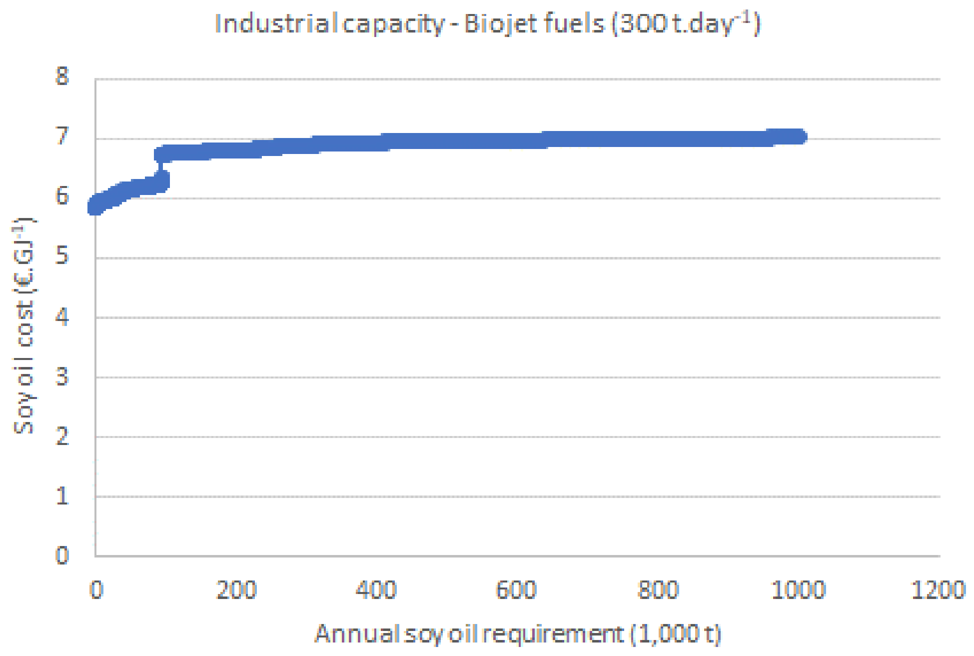
- The estimated MSPs of bio-jet fuel produced at REVAP are presented in the figure, considering the soybean oil supply from the three new processing units previously mentioned.
- The results correspond to the hypothesis that the feedstock would come exclusively from one of the processing units. As the soy oil production in Brumado would be relatively small, only a small bio-jet fuel production would be possible (7.1 thousand t.year$^{-1}$).
- As the transportation cost of soybean oil has a small impact, the difference on the MSP is small comparing the three different supply options (about 1 €.GJ$^{-1}$).

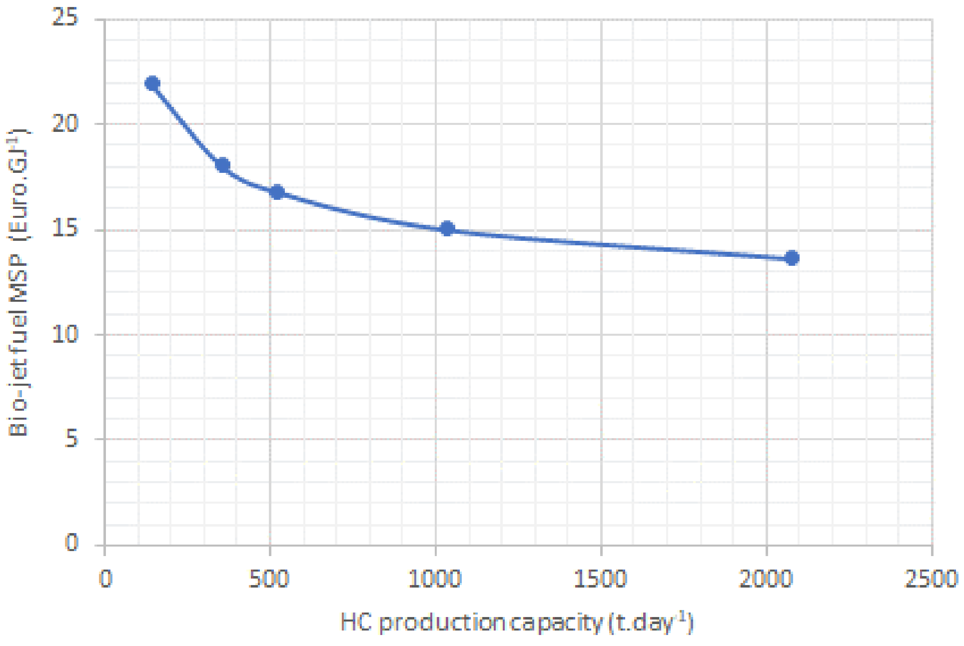
# Case Study 3 – Results for RNEST




- The average MSP vary from 14.2 to 22.1 €.GJ$^{-1}$ (609 to 945 €.t$^{-1}$). Thus, it is possible to conclude that the production of bio-jet fuels could be feasible compared to fossil jet fuels. The production of 105.1 thousand t.year$^{-1}$, at a MSP of 14.2 €.t$^{-1}$, seems to be a good result from an economic point of view.

- The estimated MSPs of bio-jet fuel produced at RNEST are presented in the figure, considering the soybean oil supply from the three new processing units previously mentioned.
- Comparing the results of the three supply sites, the difference is less than 1 €.GJ$^{-1}$, but now with a advantage for Brumado, due to the short distance.
- Comparing the results for REVAP and RNEST, it is clear that the MSP is not greatly impacted by the cost of transporting soy oil. This suggest that 1) the location of the industrial plant would be defined by other aspects (e.g. reducing carbon footprint and the proximity to international airports) and 2) and the supply of soybean oil could be diversified.




# Case Study 3 – Combined supply/RNEST

- A variant of case study 3 was developed, supposing that the supply of soybean oil can be from all three new processing plants. The analysis done is only for the production at RNEST.
- The figure on the top shows the oil supply curve up to one million t.year-1 of oil at RNEST; this is more than enough for supplying the largest industrial plant considered here (able to produce 122.6 million litres of bio-jet fuel per year).
- For the largest production capacity, the average CIF cost of soybean oil at RNEST is estimated at 6.4 €.GJ$^{-1}$ (standard deviation 0.40 €.GJ$^{-1}$). In this case, the bulk of soybean oil would come from the processing plant located in Paranaíba (71.3%, with an average cost 6.86 €.GJ$^{-1}$). The cheapest supply is from the processing plant located in Brumado (6.09 €.GJ$^{-1}$), but contributing very little in an annual basis (11%). The complement would be from the processing plant located in Presidente Venceslau (17.7%, with an average cost 6.90 €.GJ$^{-1}$).
- The figure on the bottom shows the estimated bio-jet fuel MSP. The MSP varies from 14 to 22 €.GJ$^{-1}$ (584-938 €.t$^{-1}$), as function of the industrial scale.

# Analysis of the results (1)

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

| Case | MSP (€.t$^{-1}$) | MSP (€.GJ$^{-1}$) | Production at | Feedstock (soybean oil) cost |
|---|---|---|---|---|
| 1 | 1,017 | 23.8 | REVAP | FOB price of exported oil |
| 2a[1] | 1,086 | 25.4 | REVAP | Local market price of soy oil |
| 2b[2] | 707 | 16.5 | REVAP | Local market price of soy + additional costs |
| 2b[2] | 755 | 17.6 | RNEST | Local market price of soy + additional costs |
| 3[3] | 548 | 12.8 | REVAP | Estimated costs of soy + additional costs |
| 3[4] | 584 | 13.6 | RNEST | Estimated costs of soy + additional costs |

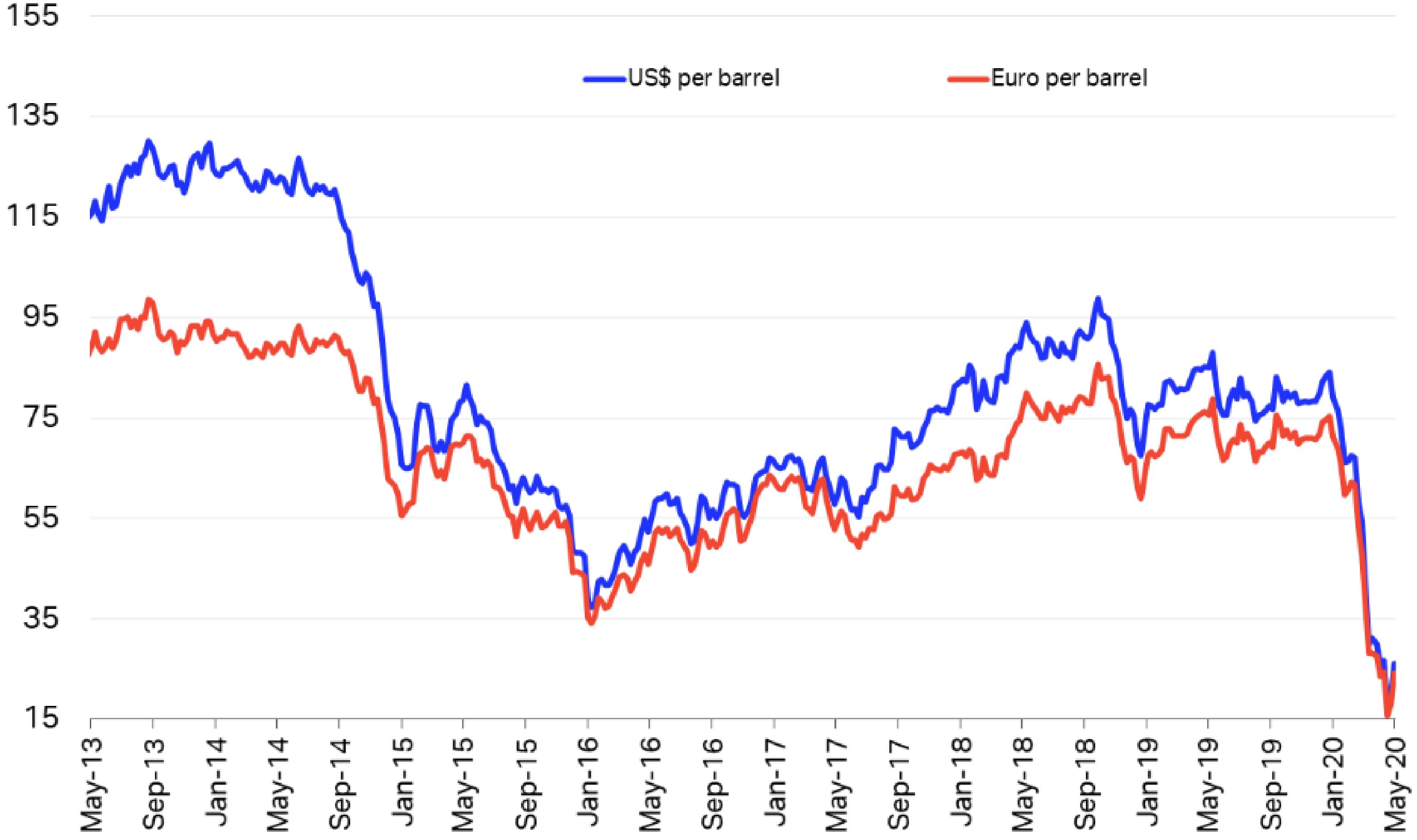
[1] Local market of soy oil at the processing unit + transportation costs from these units to the bio-jet fuel plant;
[2] Additional costs include processing costs plus transport to the bio-jet fuel plant;
[3] Estimated costs of new soybean production. Additional costs include processing costs plus transport to the bio-jet fuel plant.
[4] Estimated costs of new soybean production, supposing combined supply of different processing plants.

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

# Comparing MSPs with jet fuel prices

SAFmaps

Jet Fuel Price Currency Comparison




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

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

# Analysis of the results (2)

- From an economic point of view, the conclusion is that the production of bio-jet fuels through the HEFA-SPK pathway, from soybean oil, would be feasible in the future. But that would require a specific focus of the stakeholders on bio-jet fuels production, as soybean oil costs (e.g. its opportunity costs) have a deep impact on the results.
- Based on the assumptions done, the soybean oil cost represent 55% of the MSP of bio-jet fuels in case of the smaller industrial plants (20 $t.day^{-1}$ of bio-jet fuel) and 74% in case of the larger industrial plants (300 $t.day^{-1}$ of bio-jet fuel).
- In this sense, revenues from the sale of soybean meal would have a positive impact, potentially further reducing the MSP of bio-jet fuels. This was not considered here.

# Analysis of the results (3)

- It is worth mention that large scale production of bio-jet fuels based on HEFA-SPK from soybean oil would require an expressive amount of the feedstock. Only one plant able to produce 300 $t.day^{-1}$ of bio-jet fuel (contributing to no more than 3% of the Brazilian consumption) would require an amount equivalent to 9.3% of the soy oil production in 2018.
- The production of this additional amount of oil would require enlarging soy production by 3.3% comparing to 2018 figures, or reducing the exports of soybean by 4.9% also in comparison to 2018 figures.
- Considering the aim of producing bio-jet fuels significantly, this large soy requirement suggests the convenience of combining feedstocks (e.g. complementing the supply with macaw oil, palm oil, etc.), which would reduce risks. This solution was not explored here.

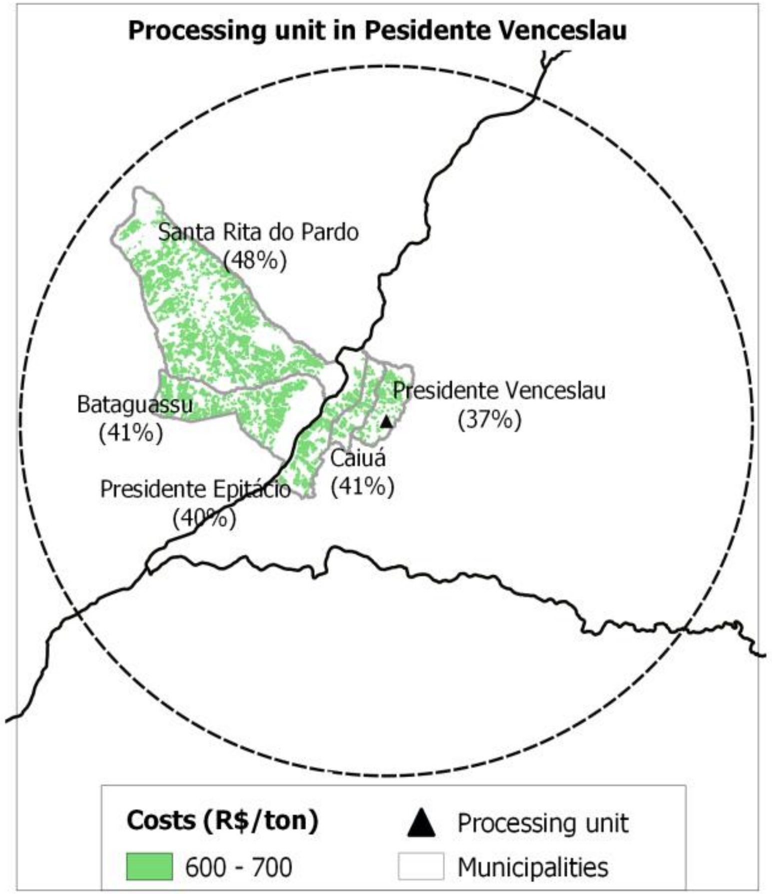
# Analysis of the results (4)

- The results of the variant of case study 3, in which combined supply (of soy oil) was considered, suggest that it would be a good strategy to have different soy processing units, conveniently located, in order to supply the industrial plant. This conclusion is reinforced by different aspects: 1) the impact of transportation costs is relatively small (both for the grain and for the soy oil); 2) it would be possible to explore the lowest segment of the supply curve in each processing units; 3) it would be possible to have small processing units; 4) it would be possible to reduce risks due to high concentration of soy cropping; 5) it would be possible to avoid large areas with monoculture around the processing units (see next slide).
- The low impact of transportation on the CIF cost of soybean oil suggests that industrial units are strategically located in relation to the existing infrastructure for the sale of bio-jet fuel (for example, airports or ports).

# Eligibility under CORSIA

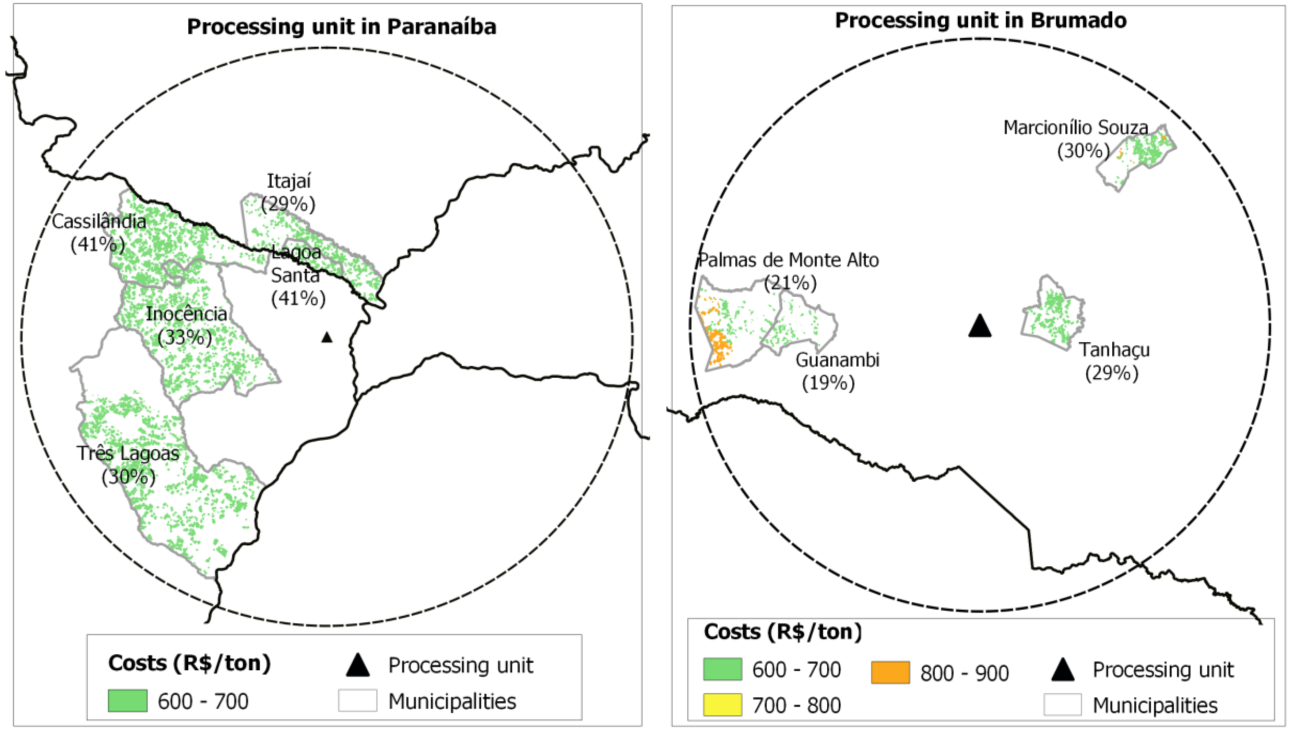
- Eligible fuels in the context of CORSIA include Sustainable Aviation Fuels (SAF) (from biomass) and Lower Carbon Aviation Fuels (LCAF) (from fossil energy sources). The production of both must be certified. For SAF, in the CORSIA pilot phase, only two principles must be accomplished (see Supplementary Material): 1) they should generate lower carbon emissions on a life cycle basis, and 2) should not be made from biomass obtained from land with high carbon stocks.
- Here, related to soy expansion (case 3), the accomplishment of Principle 2 is assured by the fact that the production would occur displacing pasturelands, and – conservatively – in areas that were not converted after first of January 2008.
- Principle 1 is assured by applying the Default Life Cycle Emissions Values: in the case of HEFA produced from soybean oil, in Brazil, the Core LCA value is 40.4 $gCO_2eq.MJ^{-1}$, while the estimated ILUC LCA is 27, 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%. Alternatively, a bio-jet fuel producer can evaluate the carbon footprint of its own production.

# The risks of extensive monoculture (1)




- Producers can be criticized for practicing extensive monocultures, despite the fact that SAF's sustainability criteria were simplified during the CORSIA's pilot phase. Here, the risk of monoculture was assessed in the context of Case Study 3 (new soybean production).
- Municipalities were identified where a large extent of the total area could be occupied by soybean cultivation.
- The most critical case could be around the processing unit to be located in Presidente Venceslau, where five municipalities could have almost (or even more) more than 40% of the total area occupied with soybeans.

# The risks of extensive monoculture (2)




- Around Brumado, in some municipalities highlighted with the potential risk of extensive monoculture (e.g. Palmas de Monte Alto), production costs are less attractive.

- The second critical case would be around Paranaíba (five municipalities with potential high cropping concentration). Around Brumado, due to the less appropriate conditions for soybean cultivation to a large extent, monoculture is expected to be less impactful.
- Technically, a logical procedure could be applied in order to avoid counting such large extensions in a single municipality. This was not done here.

# Other sustainability aspects

- In Brazil, there is a great tradition of double cropping, combining mainly soy and corn. This possibility has not been explored here. Double cultivation can lead to a reduction in soybean oil costs and, in theory, to diversification of supply, because corn oil could also be used as a feedstock for the production of bio-jet fuel.
- In the assessment presented here, the possible impacts on biodiversity would be minimized since sensitive ecosystems and preserved areas were defined as areas where feedstock production could not occur.
- The same can be said in relation to socioeconomic impacts, as indigenous reserves, afro-descendant settlements and municipalities with reported violations of land use and water use rights were assumed areas of exclusion.

# Conclusions (1)

- The reported case study shows that the production of biofuels from soybean oil may be feasible in Brazil, as long as investors focus on this objective and forget the opportunity costs related to soy and soybean oil. In this sense, it would be necessary to develop a vertical supply chain.
- As transportation costs have a small impact on economic results, it would be possible to avoid the high concentration of soy cultivation and also to seek better places, considering economic and sustainability aspects.
- In the same sense, the location of the industrial bio-jet fuel production plant must be defined according to strategic aspects, related to the opportunities for using or selling the final product.
- Even for a relatively small production of bio-jet fuel, as considered here, a large amount of soy would be needed - and, of course, soy oil. Thus, it would be convenient to consider the combination of feedstocks, an alternative that would reduce risks.

# Conclusions (2)

- In Brazil, due to the impact of taxes in feasibility assessments and, mainly, the importance and different tax policies at the regional level, an important aspect to be considered are the opportunities or restrictions that can arise from the so-called fiscal war. Here, it was considered that regional policies would be the same in all potential producing states and municipalities.
- Based on the platform database it is not possible to assess the carbon footprint of bio-jet fuel alternatives. However, the assumptions adopted (for example, soybean cropping replacing pastures, low risk ILUC actions – e.g. intensive livestock –, reduction of transportation distances, use of planted wood as fuel in processing units, etc.) are aligned with the reduction of greenhouse gas emissions and, potentially, life cycle emissions could be below the default values presented by CORSIA.

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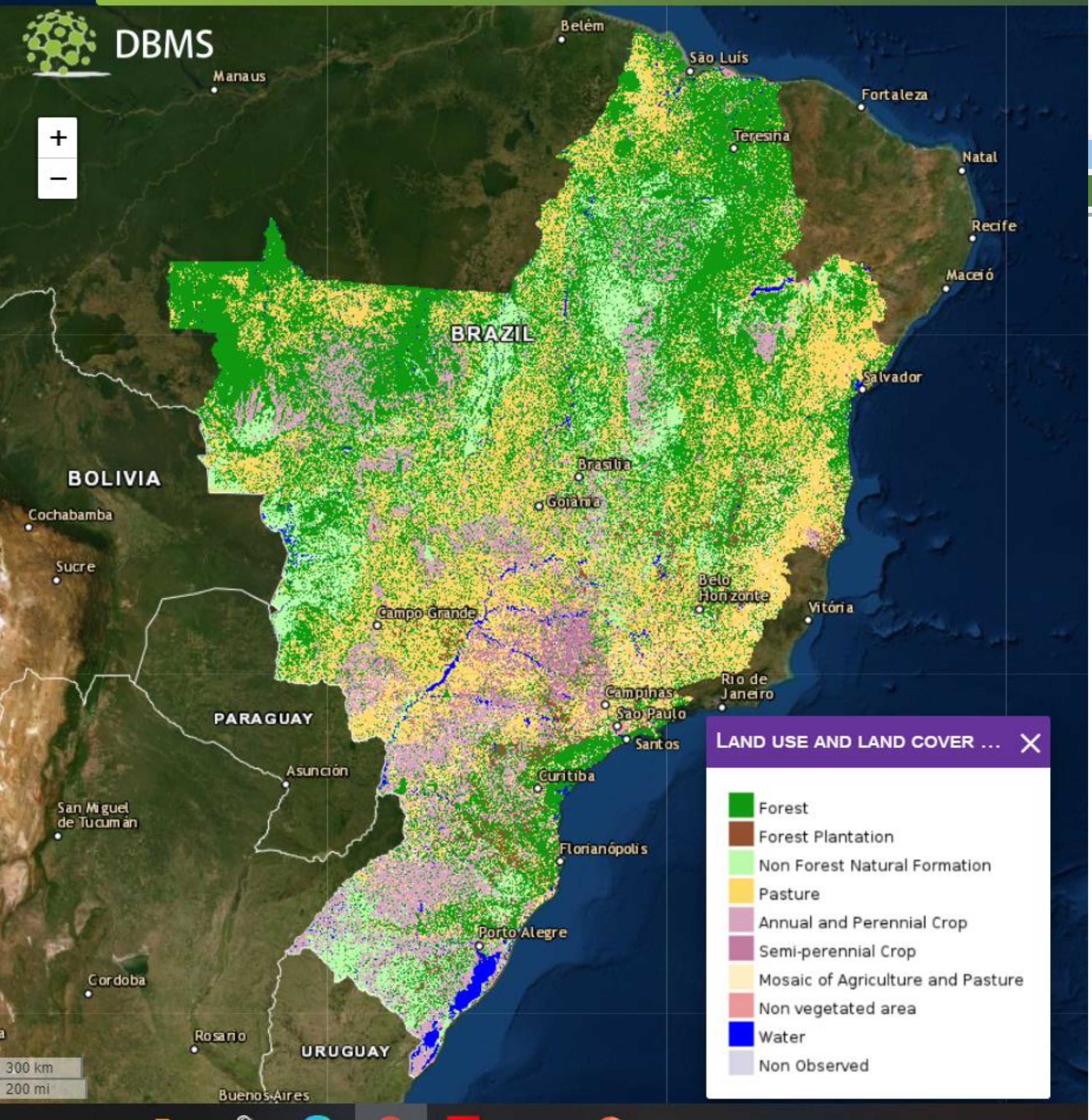
## Development of Database Management System (DBMS) for Sustainable Aviation Biofuel in Brazil

# Case study: HEFA pathway / soybean

# Supplementary Material

# List of Contents

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

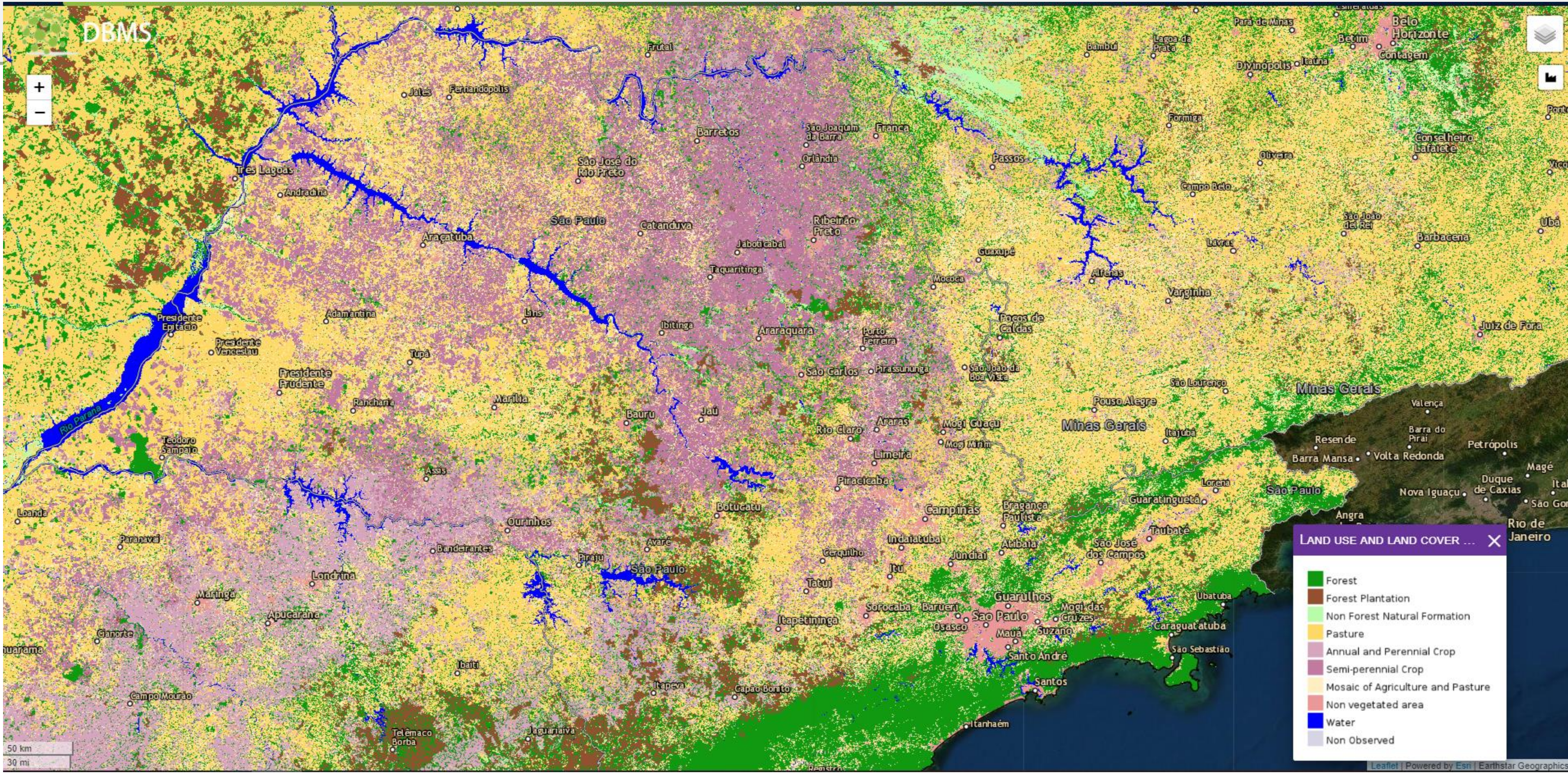



# Land use and land cover in 2018

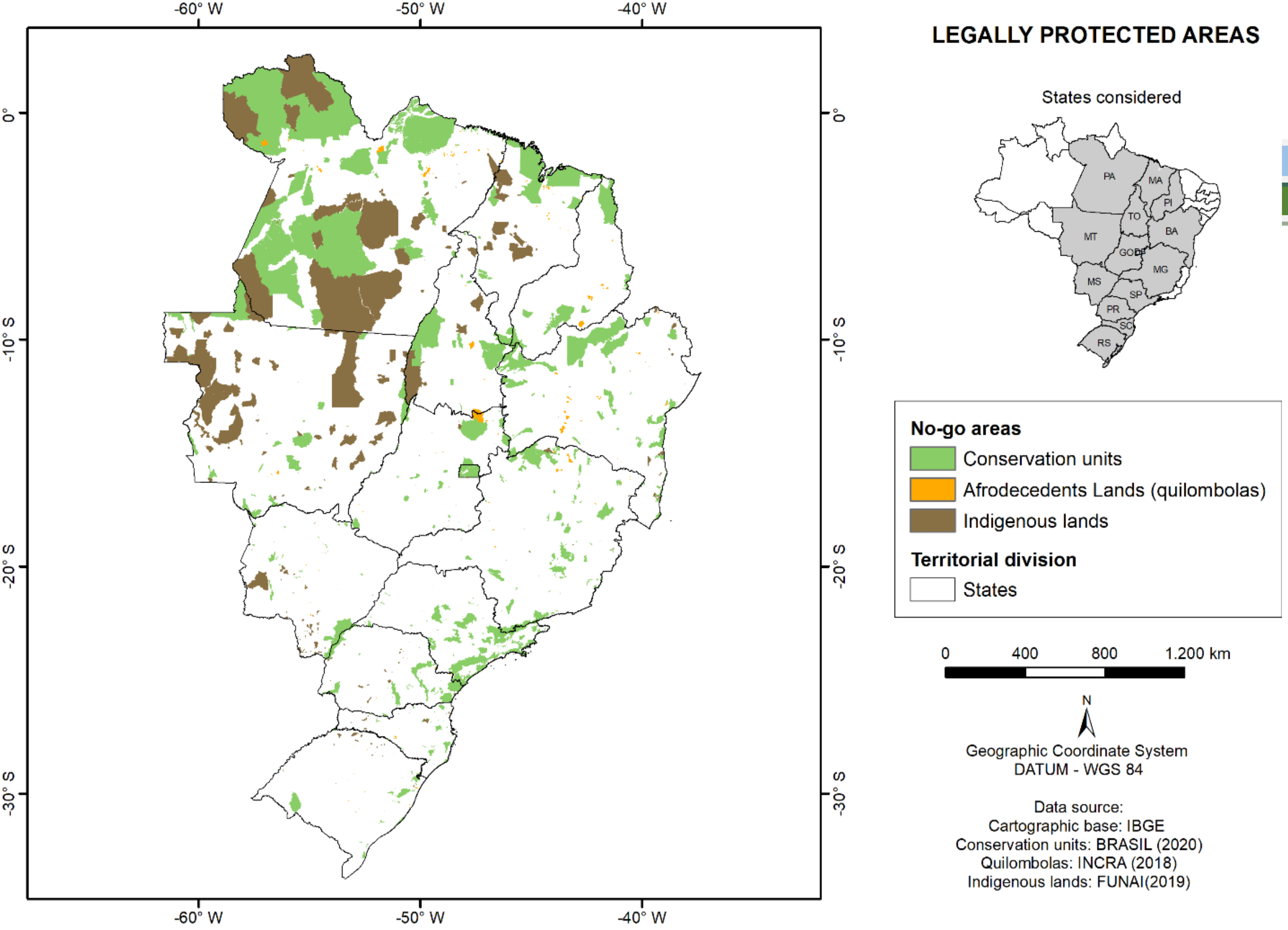
SAFmaps

- Figure shows the land use & land cover map available at the database and used in this study.
- Information of land use and land cover available at the platform database corresponds to 2018. The source is Mapbiomas.
- The next slide shows a zoom-in image for São Paulo state.

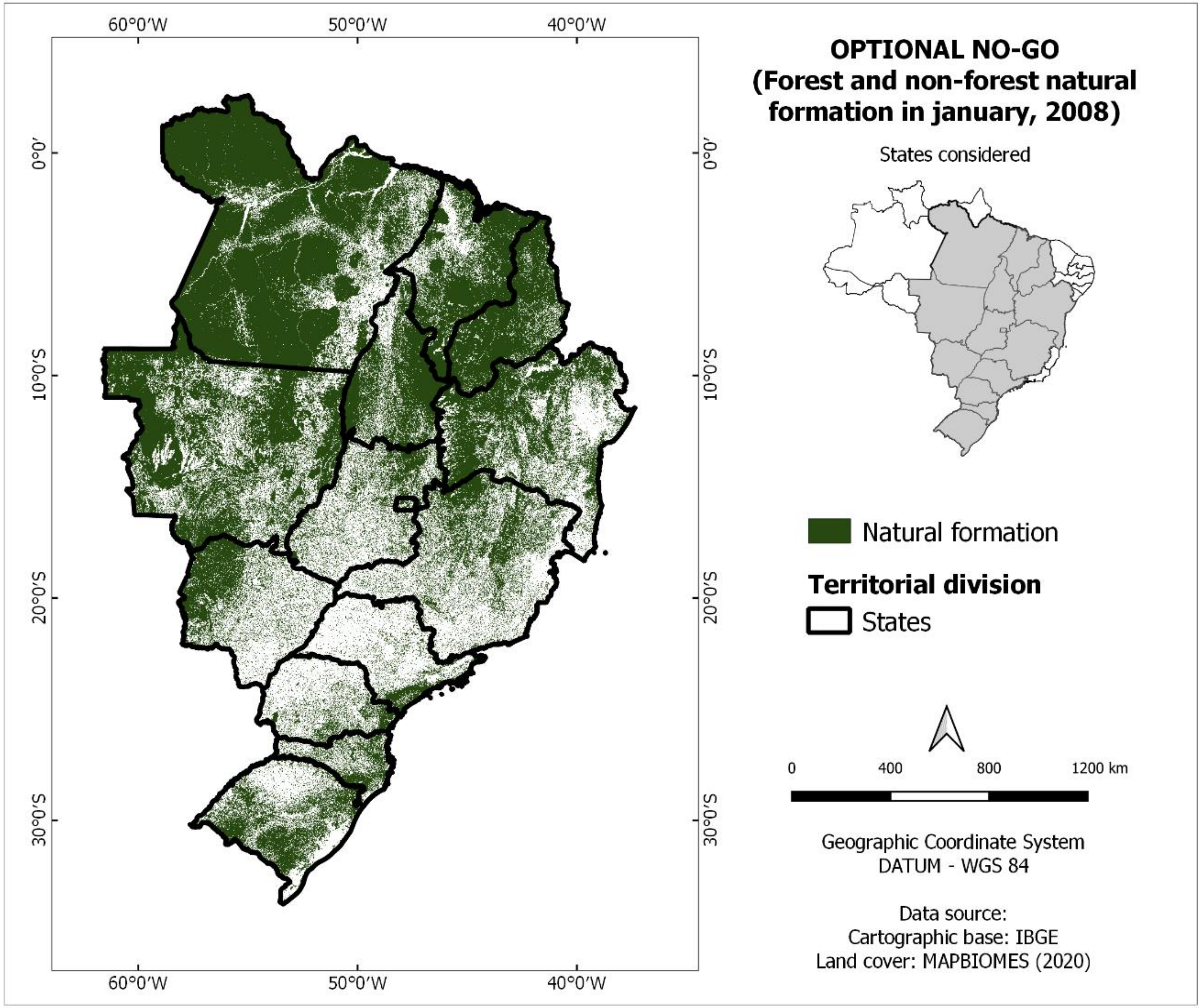
# Land use and land cover in 2018 – detailed image for São Paulo state



# Sensitive areas (1)



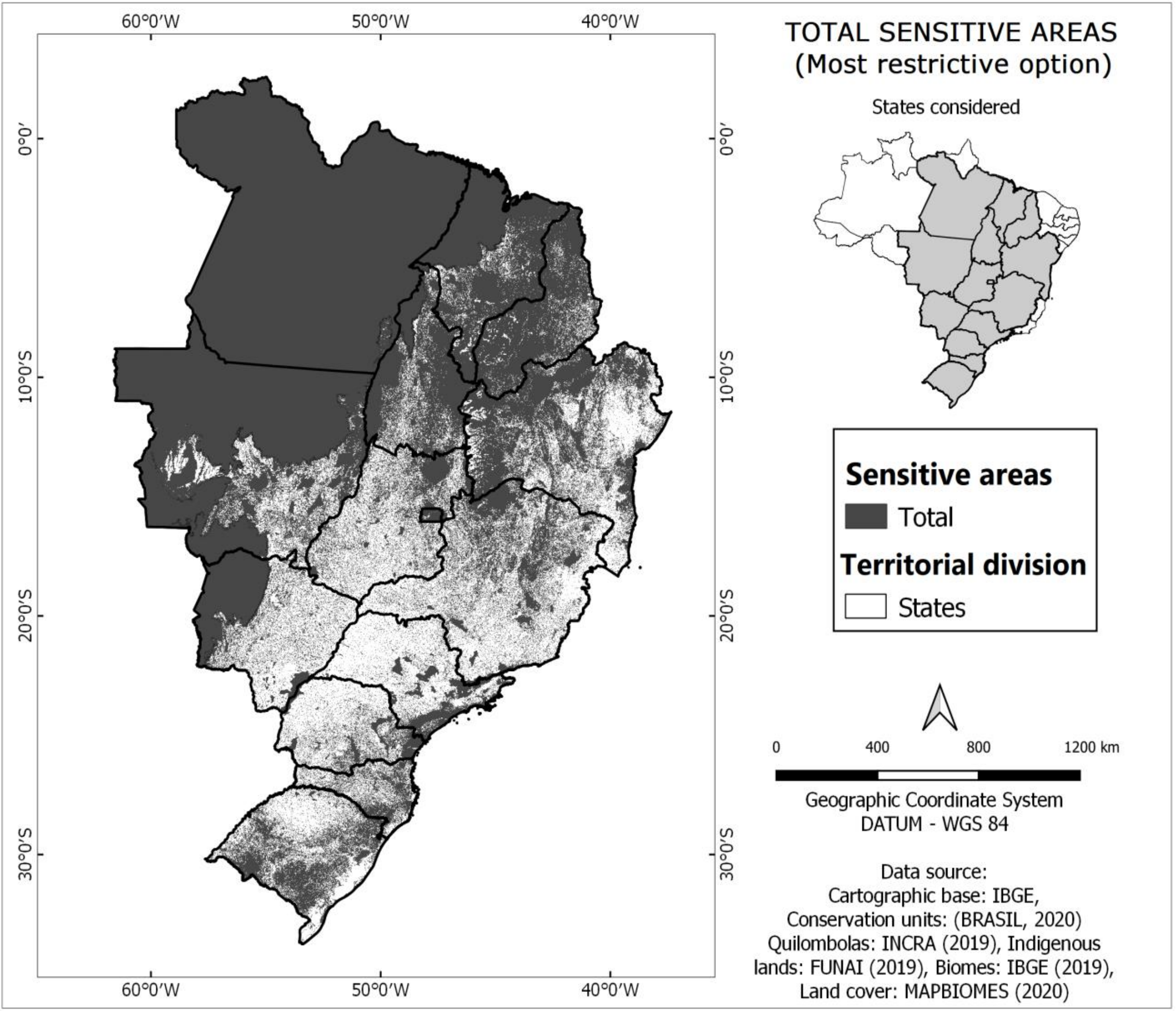

- Feedstock production cannot occur in legally protected areas.
- Legally protected areas include conservation units (for environmental reasons), the land that belongs to Afro-descendants (i.e. quilombola areas, or Afro-Brazilian settlements) and reserves of indigenous peoples.




# Sensitive areas (2)

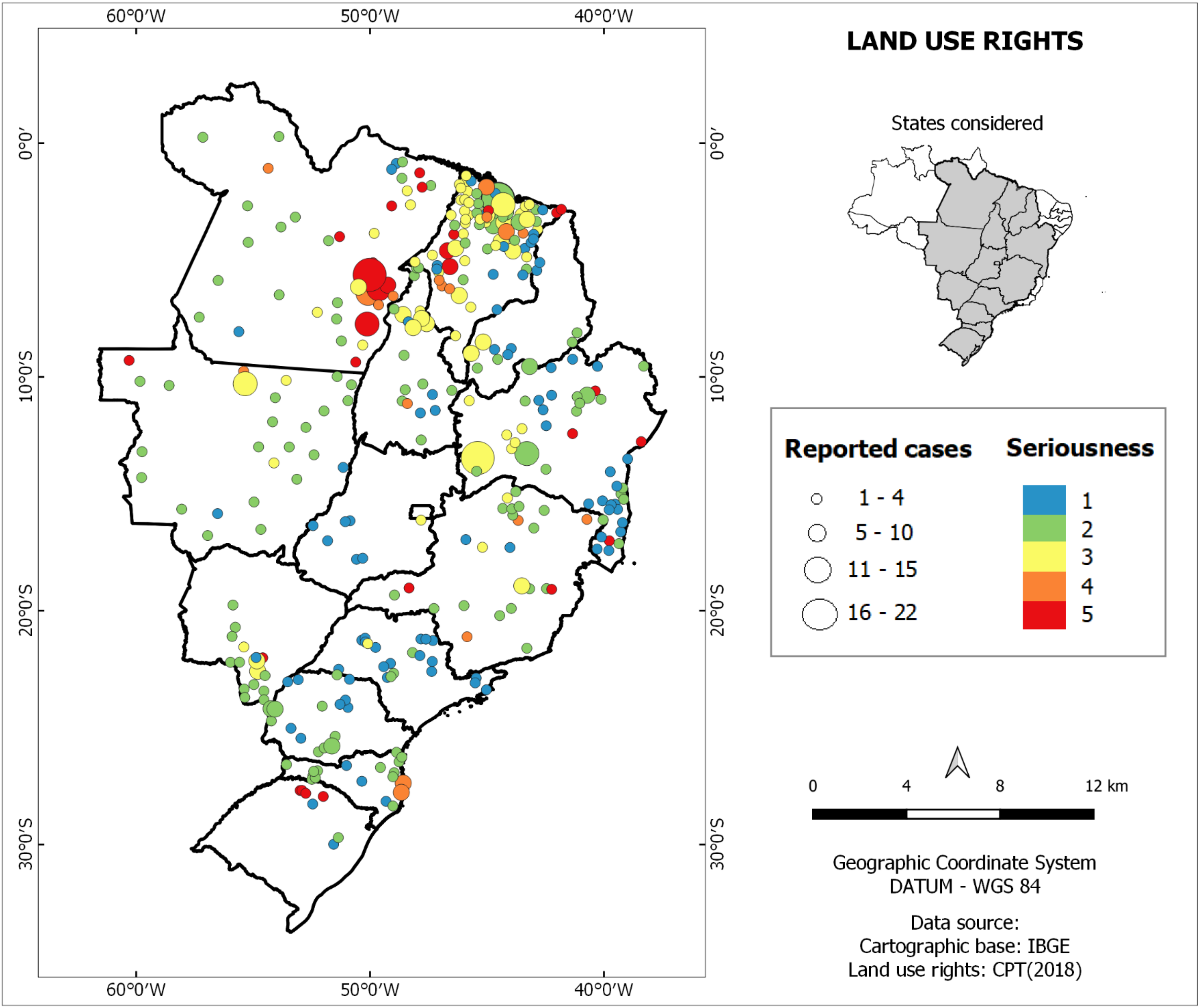
- According to CORSIA, SAF cannot be made from feedstocks obtained in certain areas (for example, primary forests, wetlands, etc.) where land was converted after January 1, 2008 (see information about CORSIA).
- In this sense, a map of land uses and land cover by the end of 2007 was used to define -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

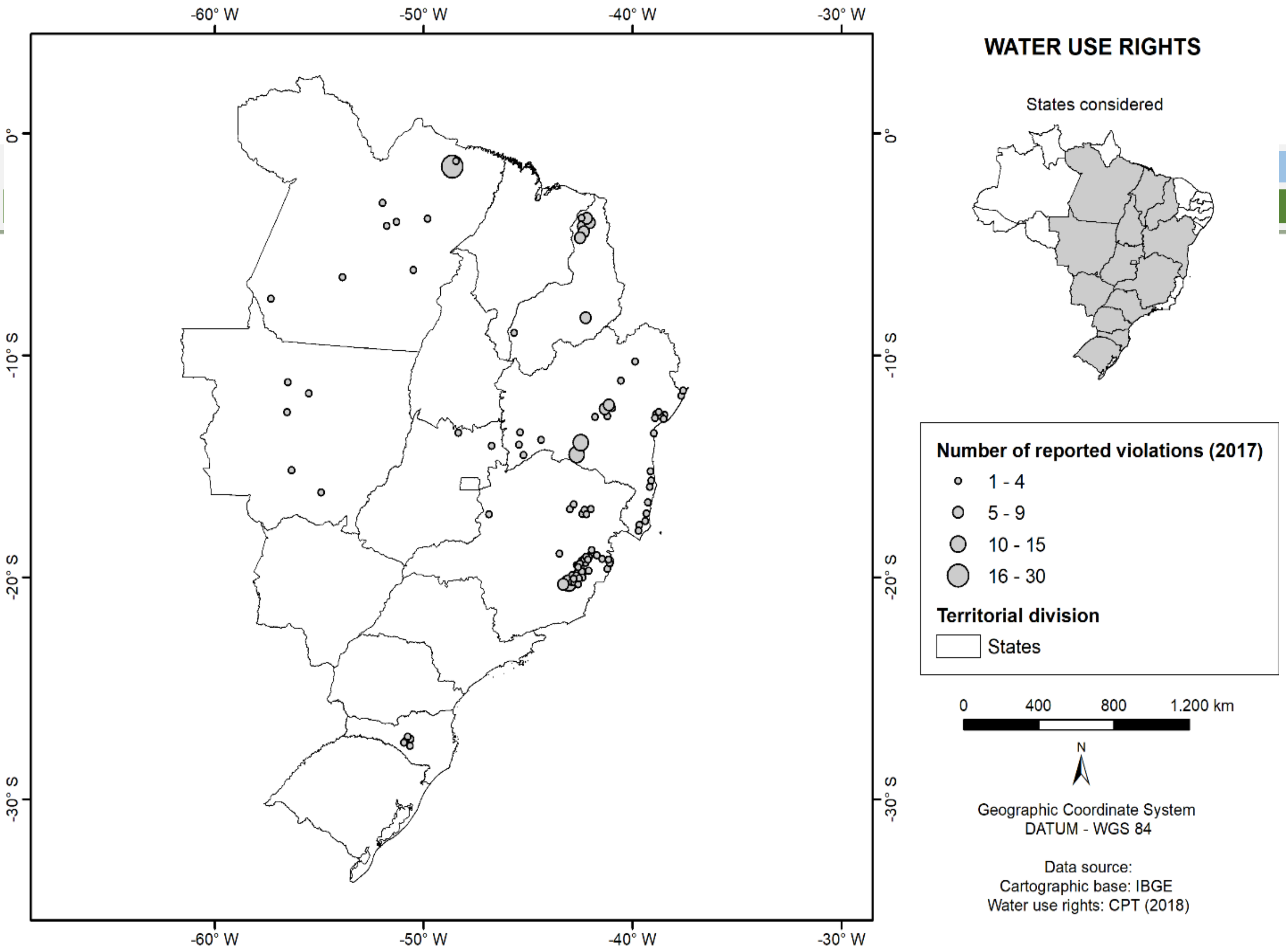



- The figure combines the previous map with areas of the biomes Amazon Forest and Pantanal, which are biodiversity hot-spots.
- In this project, this is the most restrictive option.
- Both maps include, as unusable areas for feedstock production, the lands classified as national parks, areas protected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

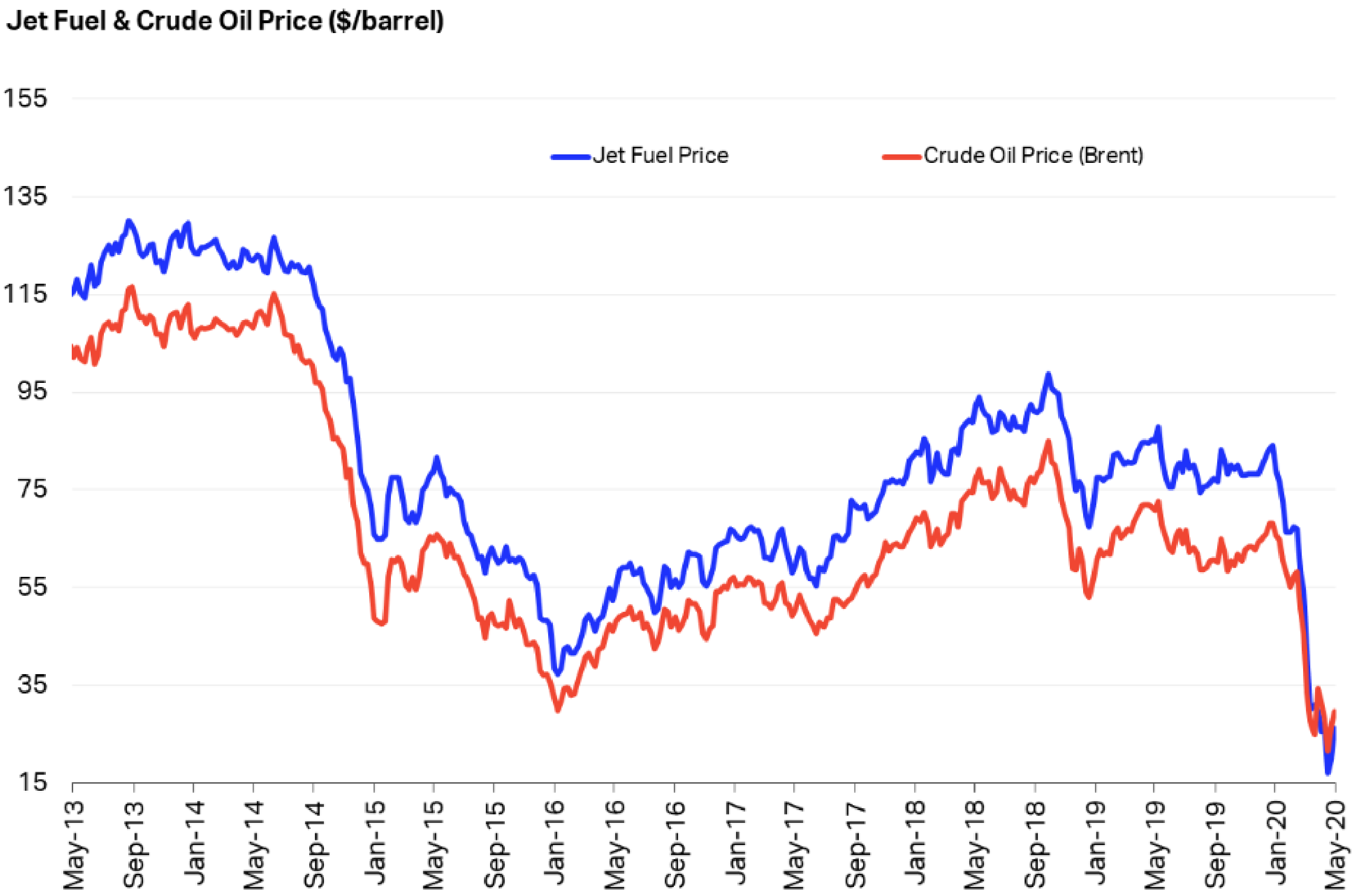



# Water use rights

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.

# Jet fuel prices: historical data and worldwide variations




Source: Platts, Datastream

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

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

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

# CORSIA and eligible fuels

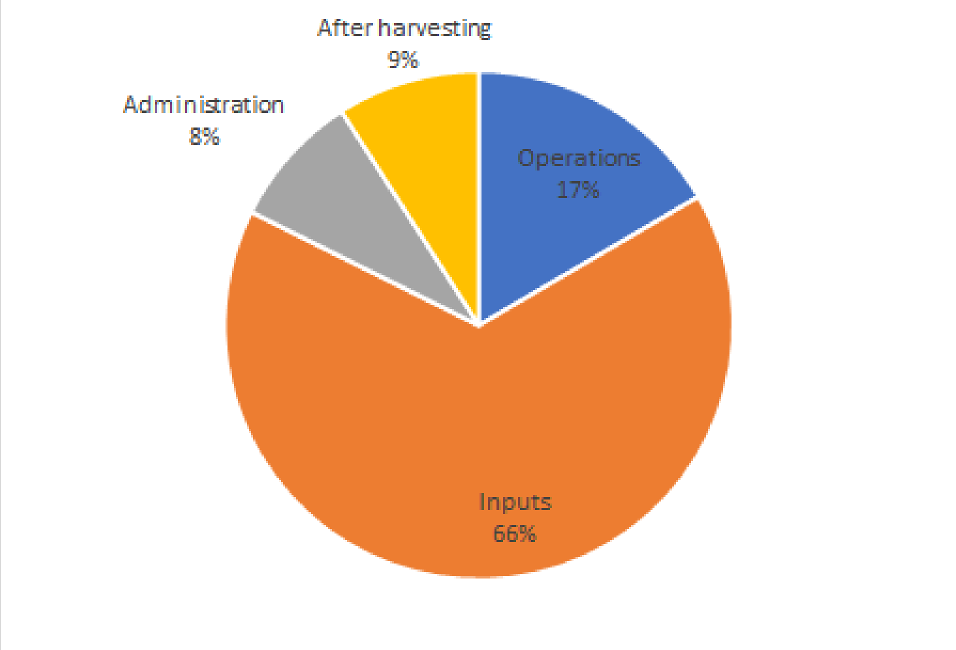
- CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) is a global market-based measure scheme adopted by ICAO Assembly, in 2016, aiming to address the increase of GHG emissions from international aviation.
- An aeroplane operator can reduce its offsetting requirements by the use 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 are presented in the table.

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

Source: CORSIA (2019)

# Agricultural costs

- For soybean production, agricultural costs were estimated based on the cost structures presented by Agrianual for different producing regions (figures for 2019, which were corrected to reflect costs in 2018). This information was used to characterize the typical costs (in 12 producing states) of sowing, crop management, harvest and short-term grain storage.
- The shares of four cost categories (on average, based on costs expressed in R$.hectare$^{-1}$) are shown in the figure. The table illustrates the highest and lowest production costs in 2018 (without considering land prices).
- Without considering land prices, the average cost was estimated at 2,649 ± 131 R$.hectare$^{-1}$ (615 ± 30 €.hectare$^{-1}$). Assuming an average yield of 3.58 t.hectare$^{-1}$, the average cost would be 714 ± 36 R$.t$^{-1}$ (172 ± 8 €.t$^{-1}$).
- Here, land prices (land used as pastures) were taken from the database available at the database, built from different sources.




| Parameter | RS | MS |
|---|---|---|
| Average yield (t.ha$^{-1}$) | 3.01 | 3.59 |
| Costs (€.ha$^{-1}$) | 652 | 568 |
| Costs (€.t$^{-1}$) | 217 | 158 |

# Industrial costs

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

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

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

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