MAPPING FEEDSTOCK AVAILABILITY FOR THE SUSTAINABLE AVIATION FUELS PRODUCTION IN BRAZIL

USED COOKING OIL

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INTRODUCTION

RELEVANCE

AMBITOUS TARGETS

The International Civil Aviation Organization (ICAO) is pursuing the GHG reduction on international flights:

- Improve fleet fuel efficiency by 1.5% per year from 2009 to 2020
- Carbon Neutral Growth from 2020
- Reduction of GHG emissions by 50% in 2050, as compared to 2005

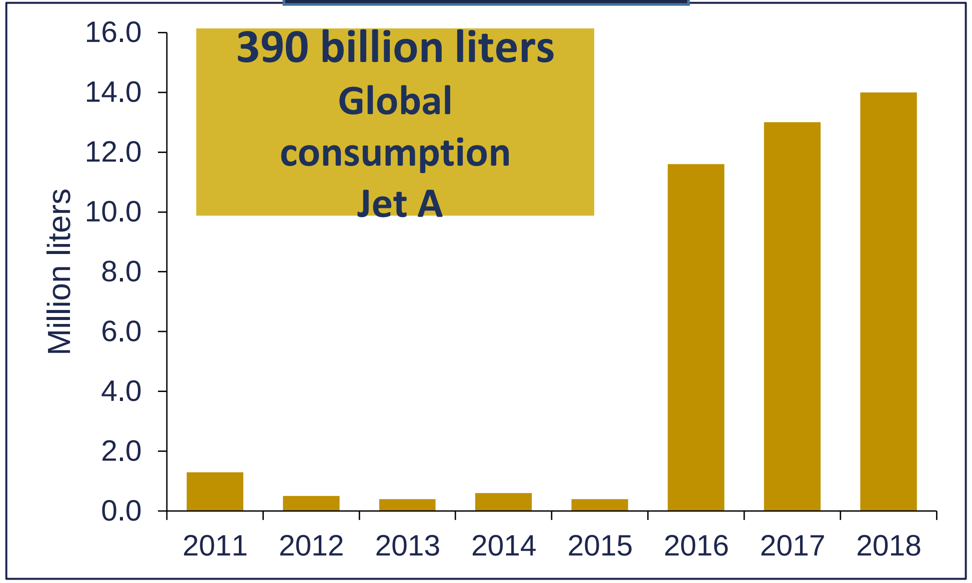
POSSIBLE PATHS

Improvements in the design and engine of aircrafts, or in the operations and infrastructure of aviation could help to achieve these targets. But they are limited.

SAF

Among the options, the substitution of fossil fuels by Sustainable Aviation Fuels (SAF) is considered the only one with the potential to achieve significant GHG reductions in the short-term.

SAF PRODUCTION



Source: ICAO (2020)

SAF must provide a reduction of, at least, 10% in GHG emissions when compared to fossil kerosene (on a life cycle basis), and must not have been obtained from high-carbon areas since 2008 (ICAO, 2019)

Thus, residual feedstocks are strategic options for significant GHG reductions, which will likely lead to low costs for SAF production.

GENERAL OBJECTIVES

IDENTIFY AND MAP

Identify and map alternative residual feedstocks for SAF production in Brazil, including CO-rich industrial off-gases, beef tallow, used cooking oil, forestry residues, and sugarcane residues (bagasse and straw).

ESTIMATE POTENTIAL USE

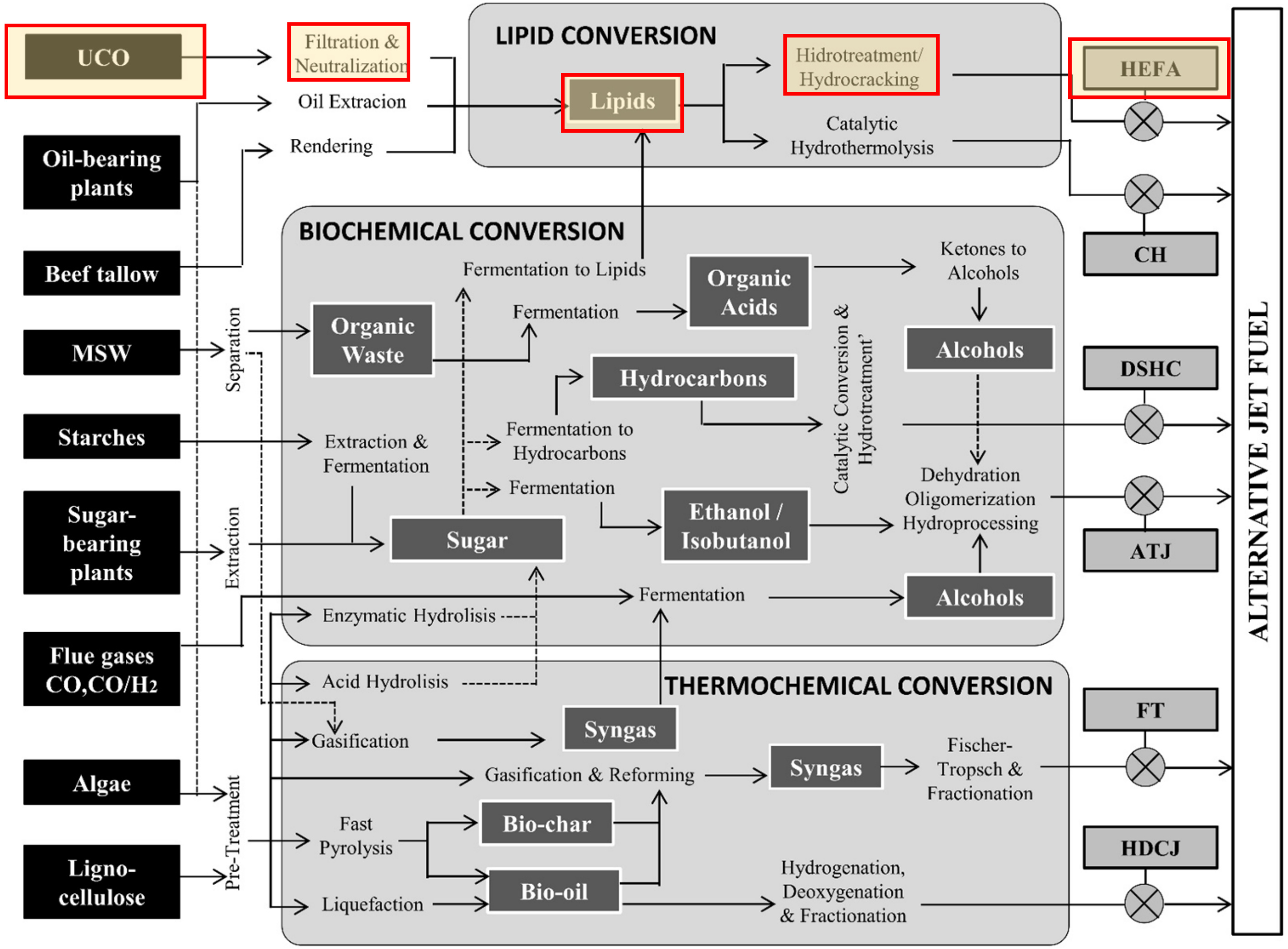
Provide information about feedstock availability and potential production of SAF.

Pathways for SAF production:

Several pathways (feedstock + conversion technology) can be used to produce SAF. Some of them are currently approved or in the pipeline for approval by ASTM. An approved pathway means that the SAF produced is certified as a drop-in fuel and can be use with fossil kerosene within blending limits (v/v).

This case study focuses on Used Cooking Oil (UCO) as a feedstock, using HEFA technology

Pathways for SAF production* Source: Boeing (2013)



** Recently, ASTM approved the co-processing of vegetable oils, greases, and Fisher-Tropsch biocrude with fossil middle distillates in oil refineries (maximum blend 5% v/v). Co-processed fuels is not represented in this figure.*

OBJECTIVE OF THIS REPORT

General objective

To map the availability of UCO for SAF production with geographical detail, thus enabling future studies on investment opportunities and strategies.

Specific objectives:

- Estimate the current production and availability of UCO from households and food services in Brazil
- Identify locations for feedstock collection and their production capacity
- Identify potential locations for processing industries (HEFA plants)
- Identify the demand (airports)
- Develop maps:
    - Spatializing the availability of UCO
    - Matching the availability of UCO with potential processing locations
    - Matching potential processing locations with the consumption sites
    - Matching all the above with transport infrastructure (gas pipelines, harbors)

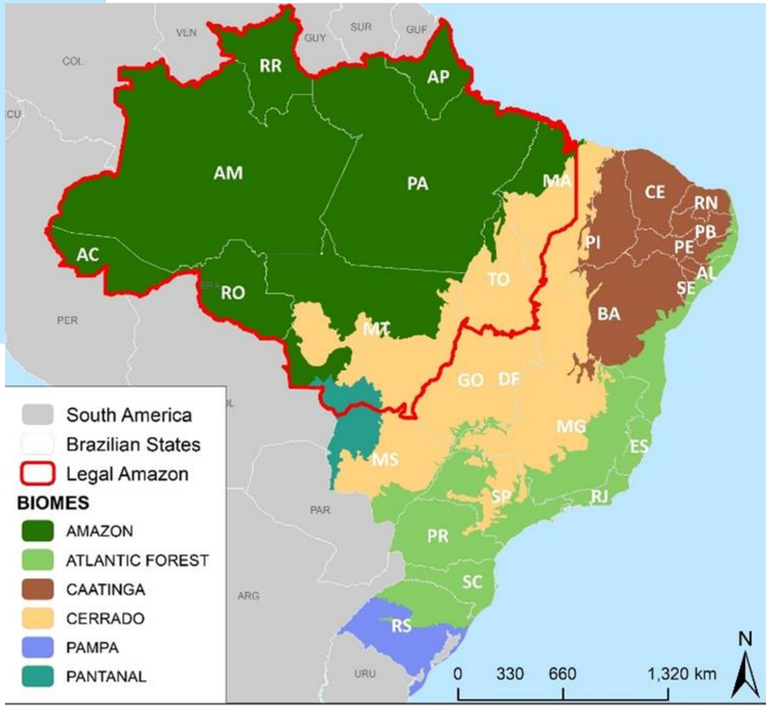
CONTEXT

GEOGRAPHY AND BOUNDARIES OF BRAZIL

The Federative Republic of **Brazil** is a country of continental dimensions, whose territory **covers around 8.5 million km²**.

Politically, **Brazil is divided into 27 federative units**, composed of 26 states and a federal district (where the national capital is located).

These federative units are subdivided into municipalities. The municipalities in the Northern region (in green) have much larger areas than in the Southeast, for example, due to historical and geographical reasons. This fact needs to be considered in order to understand the availability of feedstock, which is spatialized by municipality.



The second map displays the boundaries of the six Brazilian continental biomes: Amazon, Cerrado (or Brazilian savannah), Caatinga, Atlantic Forest, Pantanal and Pampa.

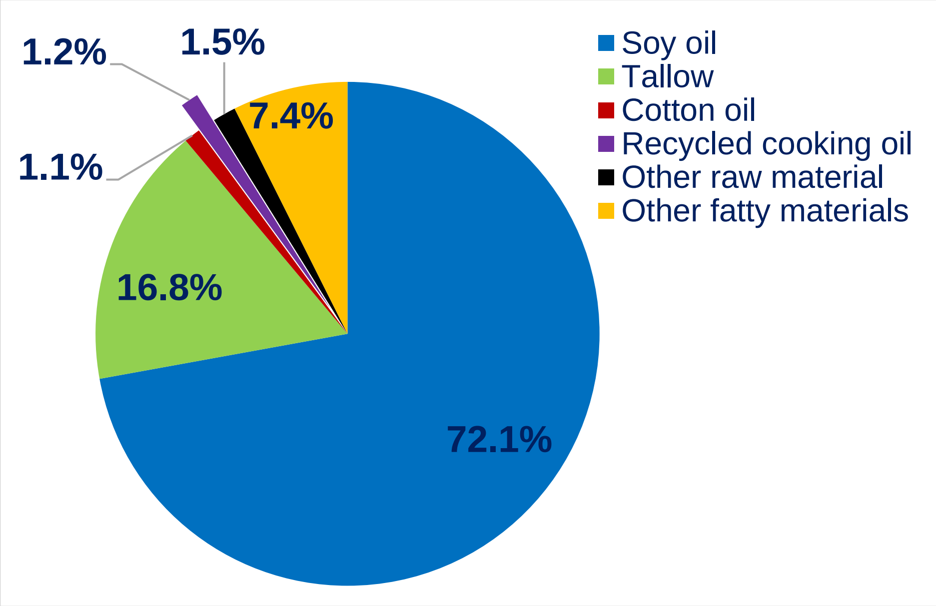
USED COOKING OIL (UCO)

WHAT IS UCO?

UCO is the remaining oil (mostly vegetable oil) used in cooking processes. This material can be obtained from households, food industries, and food services. It is currently used in the cleaning industry, for biodiesel production, or even in the processing of animal feed.

According to ABIOVE (2020), as shown in the graph, UCO corresponds to 1.2% of the raw material used for biodiesel production in Brazil. This means that, yearly, on average, **49 thousand tonnes of UCO** have been used for biodiesel production.

Average contribution of feedstocks for biodiesel production in Brazil (2015-2020)



Source: ABIOVE (2020)

The logistics for collecting UCO – which is commonly scattered among households and food services – is the main bottleneck for its further conversion into biofuel or any other product.

The potential use of UCO has been evaluated by some authors. Concilio et al. (2018) and Oliveira et al. (2014) analyzed the UCO production from restaurants in São Paulo, while Formigoni et al. (2011) focused on McDonald's potential. In turn, Zucatto et al. (2013) studied four companies involved in a supply chain for reverse logistics, while Araujo et al. (2010) estimated the logistical costs for collecting UCO from fast-food services in Rio de Janeiro.

However, due to the lack of information and proper policies, UCO, especially from households, is often improperly disposed in the sewage and common garbage, causing the pollution of the soil and water.

USED COOKING OIL (UCO) – DISPOSAL AND IMPACTS

It is one of the most environmentally damaging household products.

One liter of UCO can contaminate around 20 thousand liters of water.

More frequent floods.

Contributes to global warming.

Source: Oleoponto (2020)

According to a general estimation carried out by Óleoponto[1], more than **3.0 million tonnes of vegetable oils per year** are consumed in Brazil for food processing. Considering the lack of incentives for the collection of used cooking oil and the uncertainties related to the amount recycled and recycling actions, it is estimated that, in an optimistic context, only 3.5% to 10% is recycled. According to these surveys, 60% of people do not know how to recycle used oil, and 40% of people do not know where they can take their used oil.

One liter of oil can deplete the oxygen from up to 20 thousand liters of water (Freitas, 2016). The oil prevents the exchange of oxygen, thus causing the death of the biota, leading to the eutrophication of water bodies. An eutrophicated water body, as well as the decomposition of any organic matter, emits GHGs (greenhouse gases), such as methane, into the atmosphere. In addition, the oil waterproofs the soil, thus creating a film that hinders soil percolation and contributes to floods. In the sewage system, the presence of oil clogs the pipes and increases the costs of water and sewage treatment (Mei et al, 2011). Due to these facts, the reuse and recycling of this waste, as well as its reinsertion in new productive chains, such as that for SAF production, has environmental and social benefits.

[1] Óleoponto is a Brazilian startup created in 2017 to solve the problem of UCO disposal (https://www.oleoponto.com.br/).

USED COOKING OIL (UCO) – SOME INITIATIVES

https://bityli.com/laL3f

Ação Renove o Meio Ambiente - CARGILL

This program is managed by Cargill, a multinational company focused on food, agricultural, financial and industrial products and services. Since 2010, roughly 4.3 million liters of UCO was collected through more than 2,000 collection points spread throughout supermarkets, restaurants, NGOs, and malls in ten Brazilian States.

https://www.cargill.com.br/pt_BR/2020/4milhoes

https://bityli.com/TSdWH

Olho no Óleo – Sanitation Company from the State of Goiás

This program was recently launched by the Goiás State Governement for the collection of UCO from small and large generators in Goiânia and four other cities, with the intention to be used for biodiesel production or by the soap industry. Several collection points were placed in these cities. For each liter of UCO, the generator is granted a 0.50 cent discount credit on the wastewater treatment invoice. It is worth mentioning that around 15% of the national biodiesel production capacity is installed in Goiás.

https://bityli.com/4boqg

Biotank – Company for the collection of UCO

It is a Brazilian company focused on the collection of UCO from food establishments and mineral oil from ships.

http://biotank.com.br/index.html

Several initiatives for the collection of UCO are arising in Brazil and worldwide. It is also observed an existing market for UCO and some competition for this material in specific contexts. This potential could be better explored through a consolidated supply-chain and a clear policy and incentives for UCO collection and processing.

SUPPLY CHAIN

This study considers the collection of UCO from **food services**, restaurants and food chains, and from **households**, which is a very scattered source that depends on the habits and awareness of the population, especially due to Brazil's lack of infrastructure to collect it. At the rendering plant, the UCO is filtered for the removal of solid particles and then heated to reduce the moisture content and to obtain yellow grease.

Then, this material is transported to a HEFA plant, which is currently the best-known process for SAF production and has been tested on commercial scale. In the process, the oleaginous feedstock undergoes hydrotreatment with hydrogen in the presence of a catalyst. Unsaturated carbon-bonds are saturated, and oxygen is removed. Subsequently, the hydrocarbon chains are hydrocracked in different ranges, isomerized and, finally, generating fractioned SAF, and other products, such as diesel, naphtha, and propane. The final SAF needs to be transported to airports, where it will be blended with jet A for final consumption.

Households

Source Picture: Prefeitura de Campo dos Goytacases

Food Services

Source Picture: Universidade Metodista

UCO

Rendering plant

Source Picture: Unsplash

SAF

HEFA plant

Source Picture: Unsplash

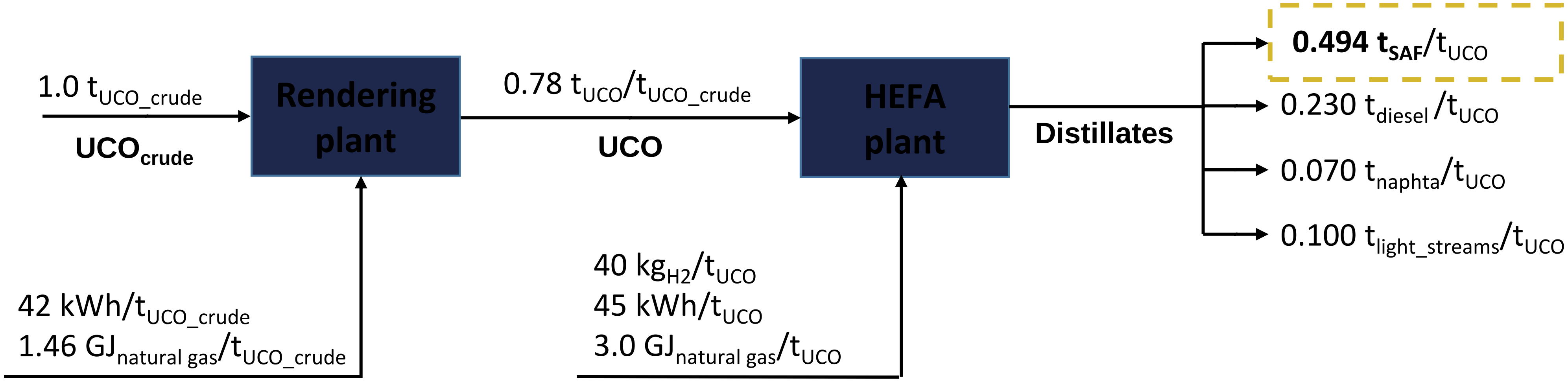
- Diesel
- Naphtha
- Light streams

SAF

Airport

Source Picture: Unsplash

SUPPLY CHAIN: General yields and inputs



Overall SAF yield

36 kg_{SAF}/t_{UCO_crude}

525 L_{SAF}/t_{UCO_crude}

Sources: Rendering plant (Seber et al., 2014); HEFA plant (Pearlson et al., 2013)

FEEDSTOCK AVAILABILITY

UCO POTENTIAL FROM HOUSEHOLDS

Brazil does not have a specific national regulation for UCO destination. The UCO collection structure is limited, specially in the context of **domestic use**, and there is a lack of information regarding the availability of used cooking oil. Therefore, the assumptions for estimating the potential availability of this feedstock were based on information gathered from interviews with sector specialists, official databases and literature reviews.

The potential UCO from households was estimated based on the **domestic consumption of vegetable oils**, according to the Family Budget Survey (POF, acronym in Portuguese), conducted by IBGE (Brazilian Institute of Geography and Statistics), which provides regional rates for vegetable oil consumption. These regional rates were assumed for each municipality in each region.

POF database (IBGE, 2019)	
Brazilian Region	**Vegetable oil Consumption (kg/capita.year)**
North	4.489
Northeast	3.982
Midwest	6.614
Southeast	5.864
South	6.135

Based on the opinion of experts[1] and literature data (Hillairet, 2016), it was assumed that:

- **35%** of the vegetable oil consumed in households can be **recovered**, as the remaining amount is retained in the food or in the cooking process;

$$UCO_{households\_recoverable} = \text{Municipality population} * \text{Consumption per capita} * \text{Share of recovery (35\%)}$$

- **10%** of the recovered amount is **collected**. Reiterating that the collection structure is not yet stablished in most parts of the country and it could be an optimistic estimate based on current Brazilian conditions.

$$UCO_{households} = UCO_{households\_recoverable} * \text{Share of collection (10\%)}$$

[1]Meeting with ABIOVE (Brazilian Association of Vegetable Oil Industries), which represents 14 companies that produce meal, vegetable oils, and biodiesel, an also cooperates in the development of sectoral policies and sustainability programs.

UCO POTENTIAL FROM FOOD SERVICE

The potential UCO from **food services** was estimated based on a European study developed by GREENEA (Hillairet, 2016). This study estimated the potential recoverable UCO from households (without collection rate) and the potential recoverable UCO from food services in all European countries, based on analyses of market experts and collectors, as well as the consolidated initiatives in these countries. As observed in the table below, the relative contribution of UCO sources varies substantially.

Considering similarities with some European countries related to the culinary and way of life, and the large incipient initiatives for UCO collection in Brazil, it was assumed that **50%** of the recoverable UCO from households would correspond to the potential recoverable UCO from food services. It is worth mentioning that food services comprise restaurants (fast food bars, traditional places and catering), food-processing industries, and supermarkets and hypermarkets.

$$UCO_{food\_service} = UCO_{households\_recoverable} * 0.5$$

The **total UCO potential availability** comprises the potential from households and food services for each municipality.

$$UCO_{total} = UCO_{households} + UCO_{food\_service}$$

Contribution of households and food services to UCO delivery for other uses in some European countries (Hillairet, 2016)

Countries	$UCO_{recoverable}$ from households	$UCO_{recoverable}$ from food services	
France	50%	50%	1.00
Germany	29%	71%	2.45
Italy	69%	31%	0.45
Portugal	50%	50%	1.00
Spain	75%	25%	0.33
UK	27%	73%	2.70

POTENTIAL AVAILABILITY FROM HOUSEHOLDS

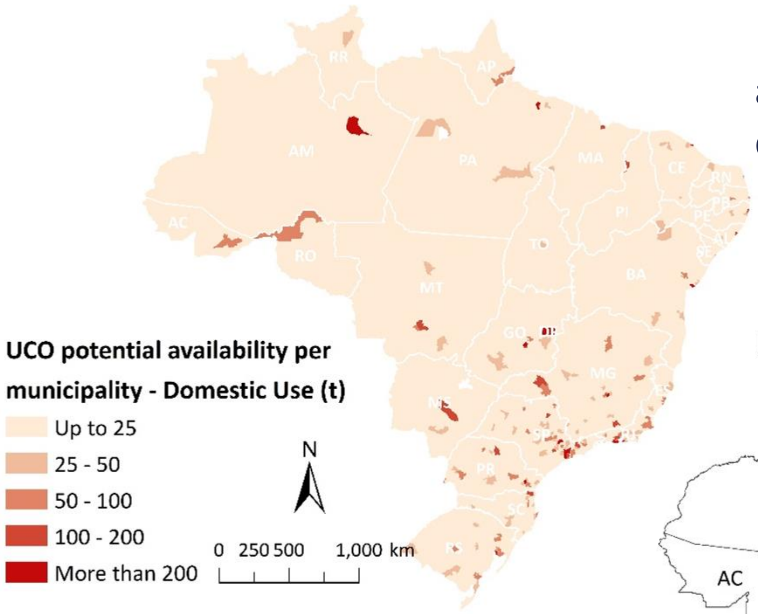
35

thousand tonnes of UCO from **households** by applying a collection rate of 10%

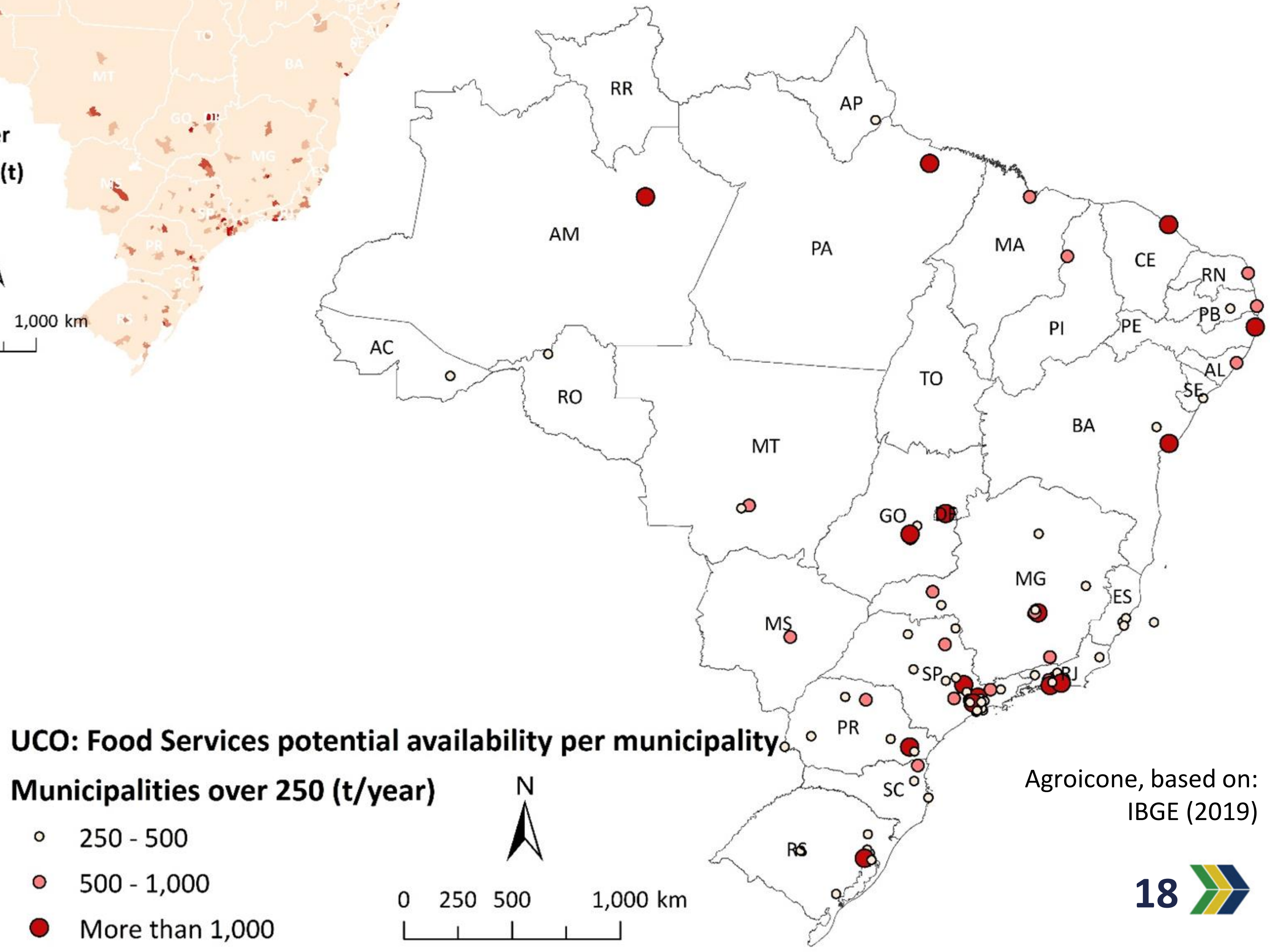
Top 10 municipalities				
Region	**State**	**Municipality**	**Habitants**	**UCO Potential (t/year)**
Southeast	SP	São Paulo	11,253,503	2,309
Southeast	RJ	Rio de Janeiro	6,320,446	1,297
Midwest	DF	Brasília	2,570,160	594
Southeast	MG	Belo Horizonte	2,375,151	487
South	PR	Curitiba	1,751,907	376
Northeast	BA	Salvador	2,675,656	372
Northeast	CE	Fortaleza	2,452,185	341
South	RS	Porto Alegre	1,409,351	302
Midwest	GO	Goiânia	1,302,001	301
North	AM	Manaus	1,802,014	283

Source

IBGE (2019)



In the map below, municipalities with feedstock availability lower than 250 t/year were arbitrarily disregarded to provide better visualization.



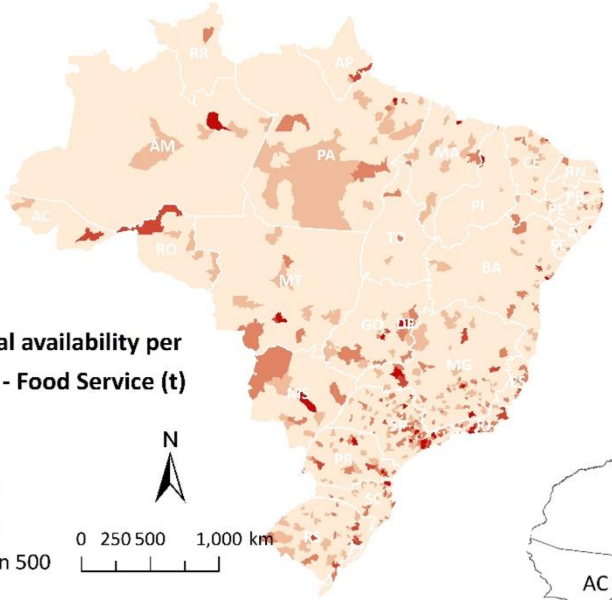
Agroicone, based on: IBGE (2019)

POTENTIAL AVAILABILITY FROM FOOD SERVICES

177

thousand tonnes of UCO from **food services**

Top 10 municipalities				
Region	**State**	**Municipality**	**Habitants**	**UCO Potential (t/year)**
Southeast	SP	São Paulo	11,253,503	11,548
Southeast	RJ	Rio de Janeiro	6,320,446	6,486
Midwest	DF	Brasília	2,570,160	2,975
Southeast	MG	Belo Horizonte	2,375,151	2,437
South	PR	Curitiba	1,751,907	1,881
Northeast	BA	Salvador	2,675,656	1,865
Northeast	CE	Fortaleza	2,452,185	1,709
South	RS	Porto Alegre	1,409,351	1,513
Midwest	GO	Goiânia	1,302,001	1,507
North	AM	Manaus	1,802,014	1,416



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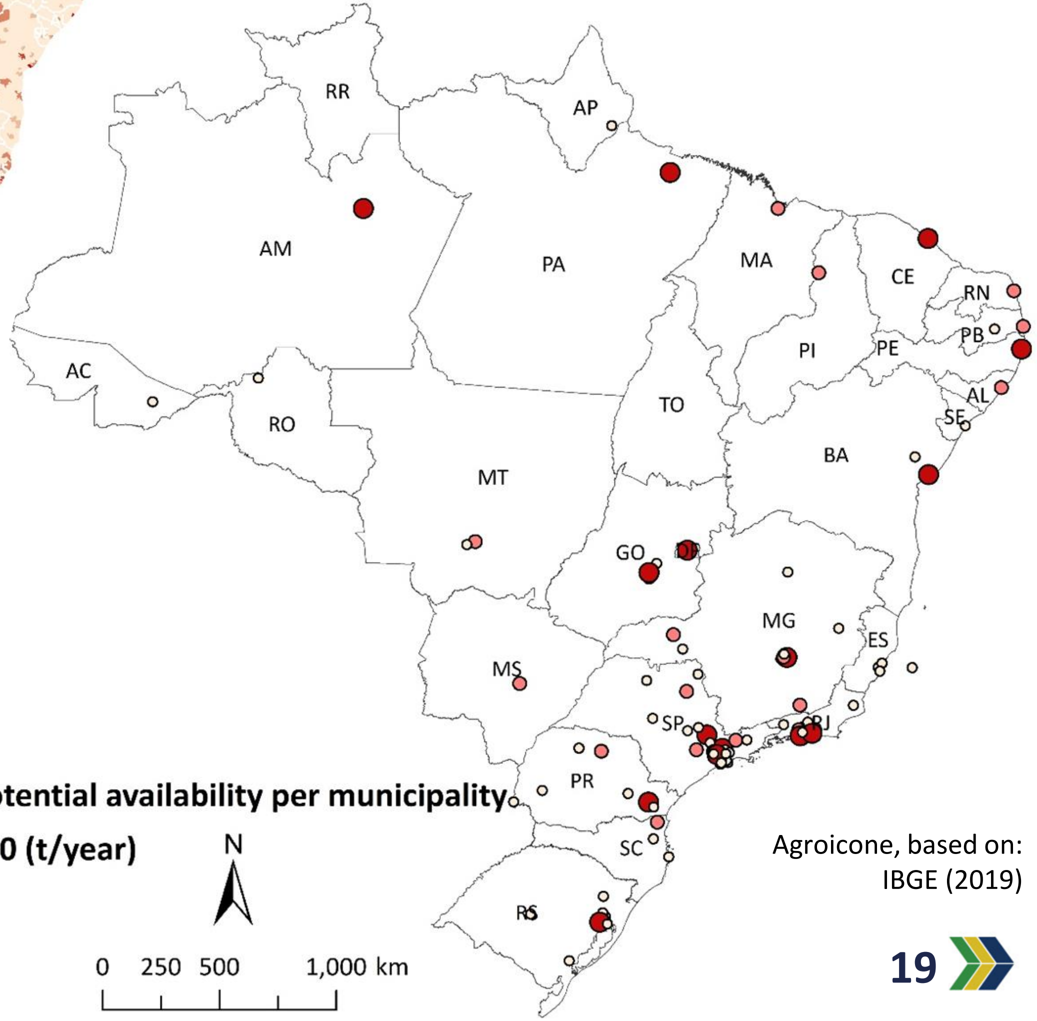


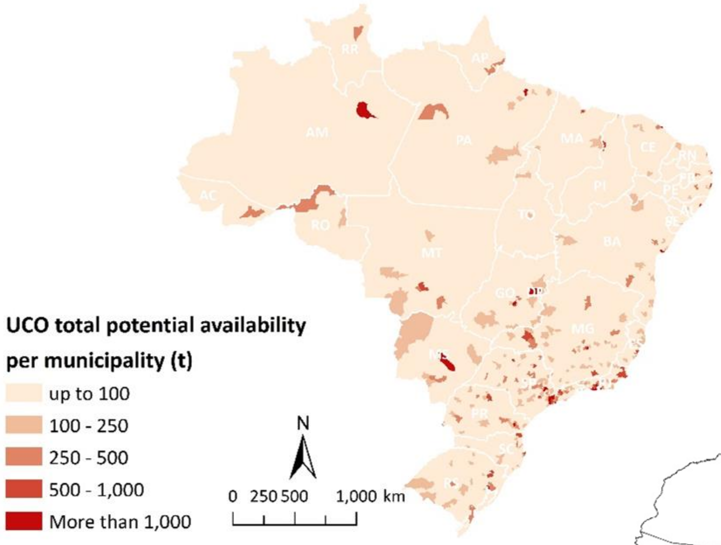
Agroicone, based on: IBGE (2019)

Source

IBGE (2019)

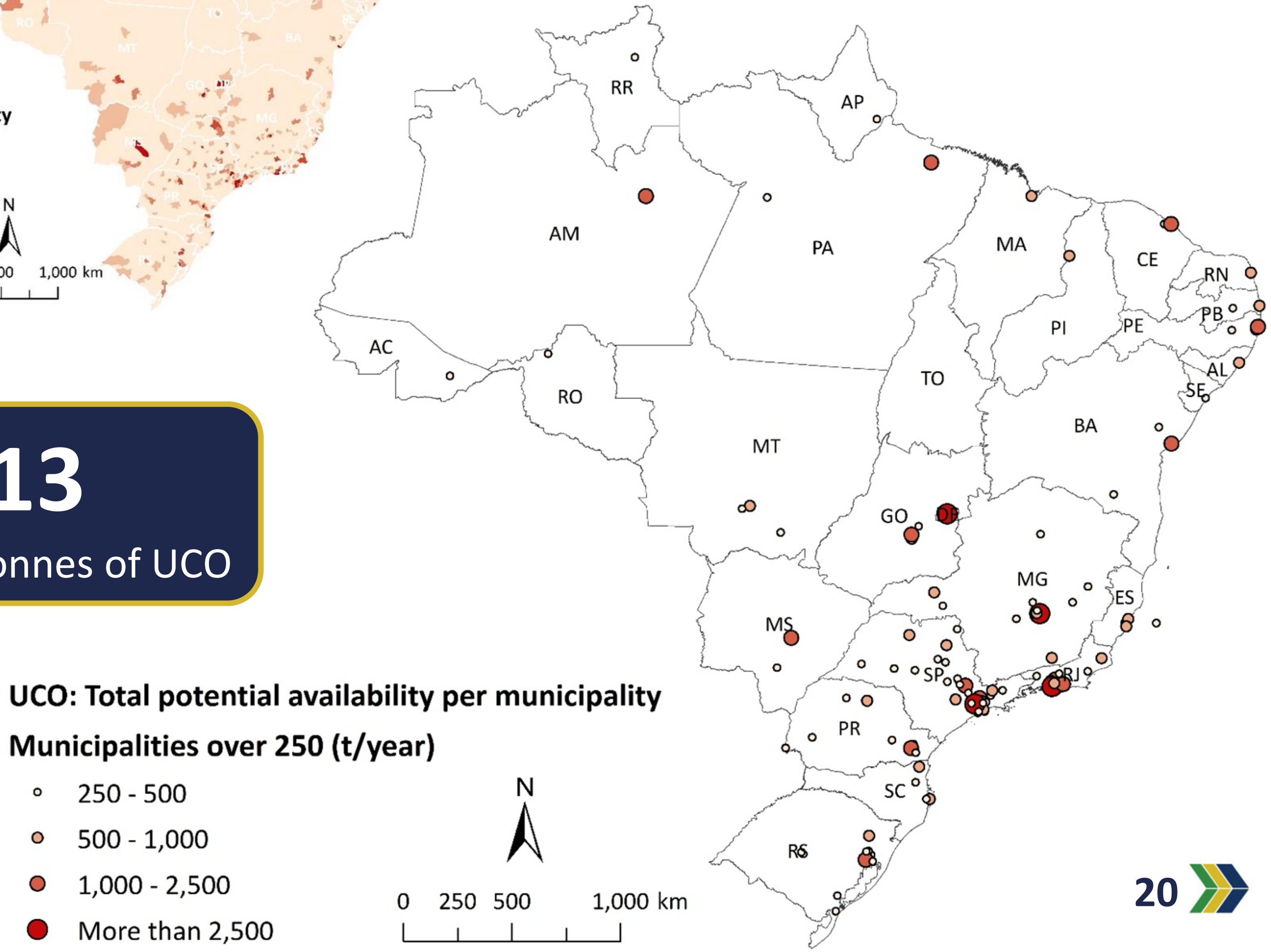
TOTAL POTENTIAL AVAILABILITY

More than one thousand metric tons per year				
Region	**State**	**Municipality**	**Habitants**	**UCO Potential (10^3 t/year)**
Southeast	SP	São Paulo	11,253,503	13.86
Southeast	RJ	Rio de Janeiro	6,320,446	7.78
Midwest	DF	Brasília	2,570,160	3.57
Southeast	MG	Belo Horizonte	2,375,151	2.92
South	PR	Curitiba	1,751,907	2.26
Northeast	BA	Salvador	2,675,656	2.24
Northeast	CE	Fortaleza	2,452,185	2.05
South	RS	Porto Alegre	1,409,351	1.82
Midwest	GO	Goiânia	1,302,001	1.81
North	AM	Manaus	1,802,014	1.70
Southeast	SP	Guarulhos	1,221,979	1.50
Southeast	SP	Campinas	1,080,113	1.33
North	PA	Belém	1,393,399	1.31
Northeast	PE	Recife	1,537,704	1.29
Southeast	RJ	São Gonçalo	999,728	1.23
Midwest	MS	Campo Grande	786,797	1.09
Southeast	RJ	Duque de Caxias	855,048	1.05



213
thousand tonnes of UCO

In the map below, municipalities with feedstock availability lower than 250 t/year were arbitrarily disregarded to provide better visualization.



MATCHING FEEDSTOCK AVAILABILITY WITH PROCESSING SITES AND DEMAND

GENERAL ASSUMPTIONS

Regarding the SAF production from UCO, the spatially explicit data of feedstock availability was combined with possible processing sites and consumers according to the following assumptions:

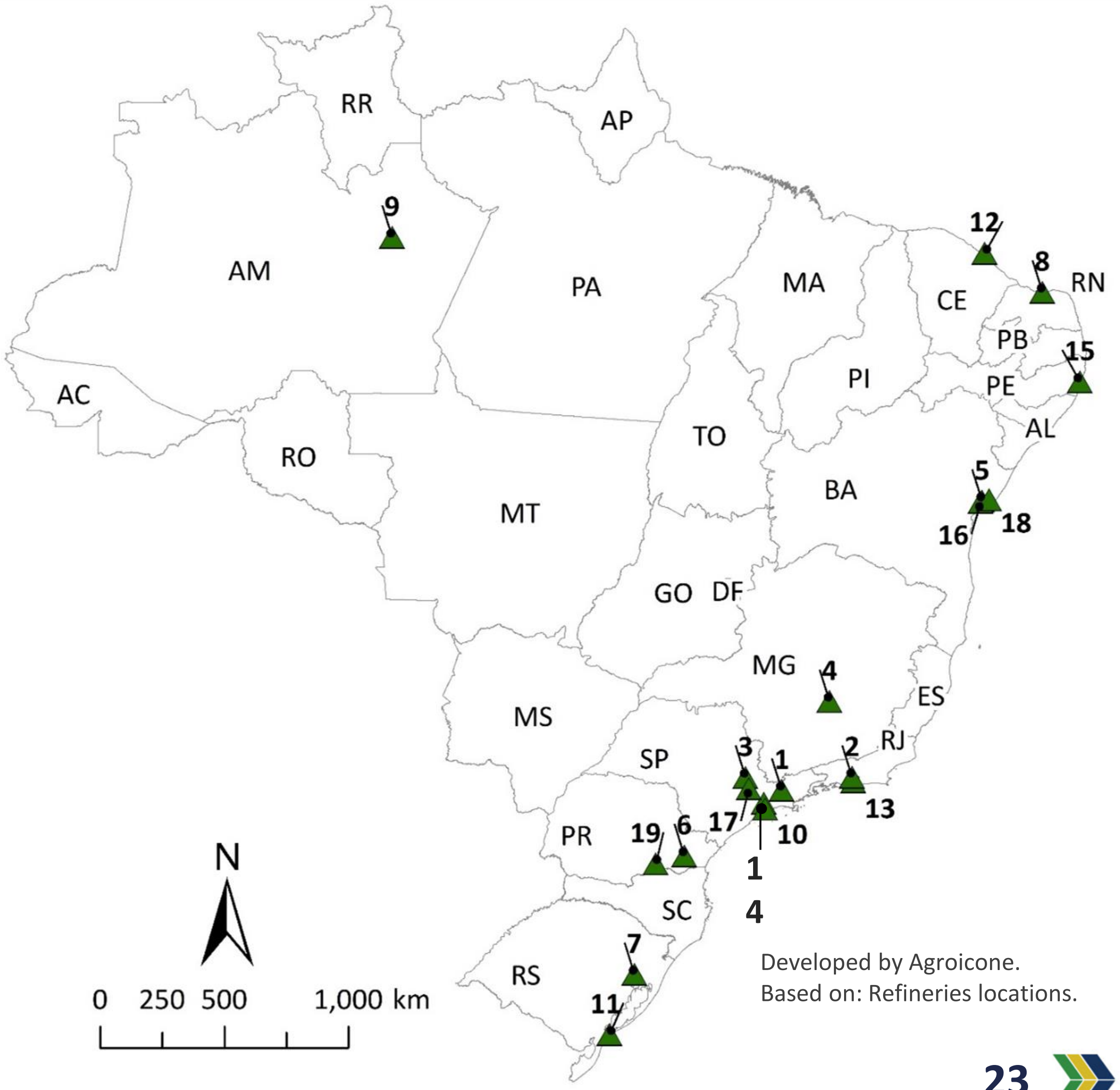
- UCO would be collected from households and food services.
- HEFA plant, where UCO is converted into SAF, should be close to an oil refinery due to hydrogen demand for hydrotreating process and process integration possibilities.
- Alternatively, HEFA plants may be located near natural gas pipelines for possible hydrogen production through Steam Methane Reform.
- Before to supply an aircraft, SAF must be blended with Jet A.
- Considering that the GHG reduction targets are related to international flights, only the international airports' supply was considered here.

OIL REFINERIES

According to ANP (2019), the map present the of the Brazilian oil refineries.

The refineries that had no production of Jet A were not considered for the following evaluations.

ID	Brazilian Refineries	Jet A Production 2018 (Million m³)
1	Revap (SP)	1.93
2	Reduc (RJ)	1.43
3	Replan (SP)	1.13
4	Regap (MG)	0.71
5	Rlam (BA)	0.36
6	Repar (PR)	0.27
7	Refap (RS)	0.21
8	RPCC (RN)	0.20
9	Reman (AM)	0.13
10	RPBC (SP)	0.02
11	Riograndense (RS)	0
12	Lubnor (CE)	0
13	Manguinhos (RJ)	0
14	Recap (SP)	0
15	Rnest (PE)	0
16	Fasf (BA)	0
17	Univen (SP)	0
18	Dax Oil (BA)	0
19	Six (PR)	0



Developed by Agroicone.
Based on: Refineries locations.

Source

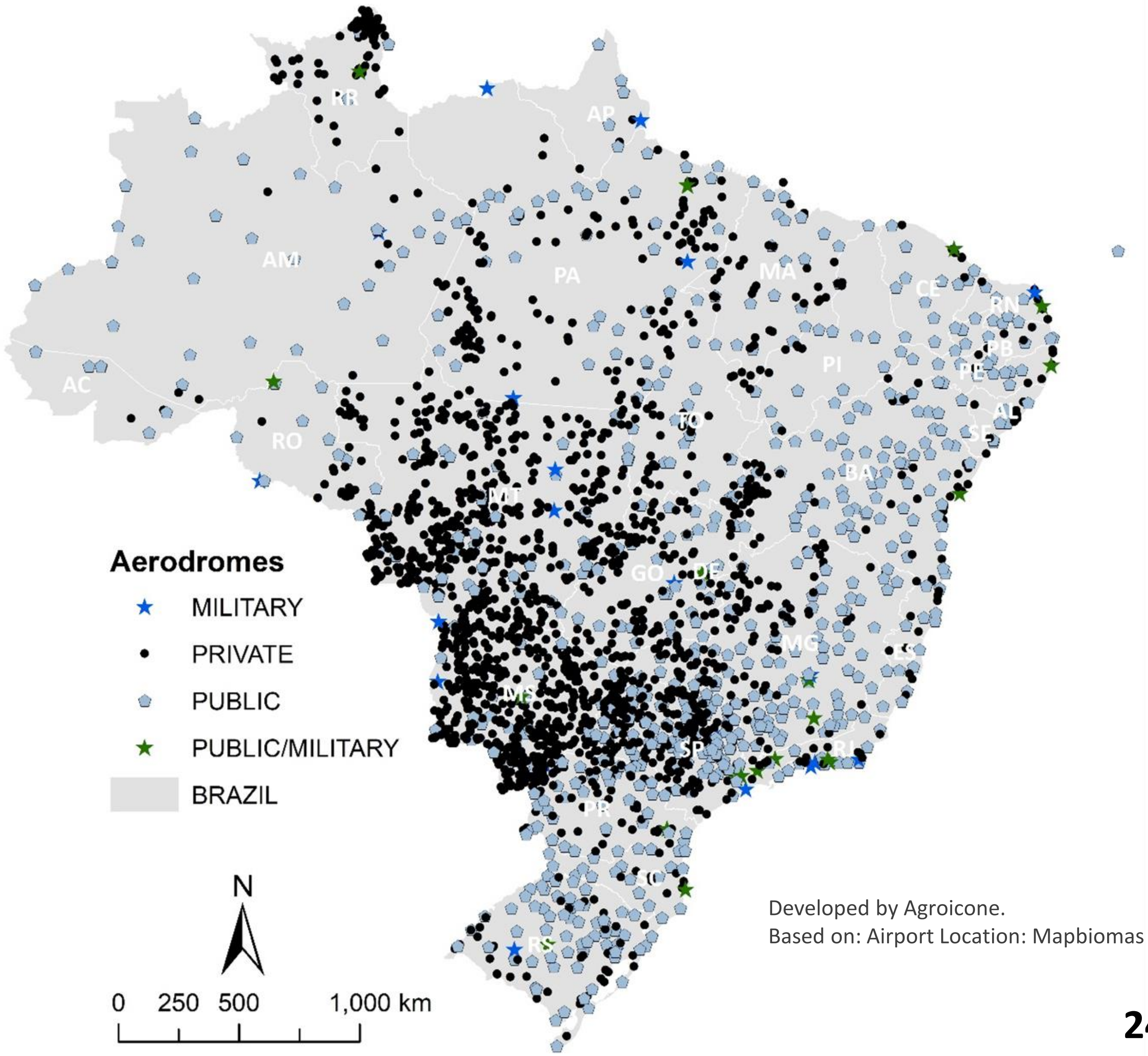
ANP (2019)

AIRPORTS LOCATION

Brazil has more than 2600 registered aerodromes, from those at least 650 are public, 1900 are private and 40 are military.

In 2018 ANAC (National Agency for Civil Aviation) registered the Jet A consumption of 143 airports, from which **34 are international airports**.

The ANAC database was used to categorize the International Airports.



Developed by Agroicone.
Based on: Airport Location: Mapbiomas (2018)

JET A CONSUMPTION AND AIRPORTS

According to The Global Economy (2020), Brazil consumed an average of 123.46 thousand barrels per day of Jet fuel in 2018, whereas the world average, based on 43 countries, is 98.57 thousand barrels per day. Out of the 43 countries analyzed by this research group, Brazil is the 10th highest consumer of Jet fuel.

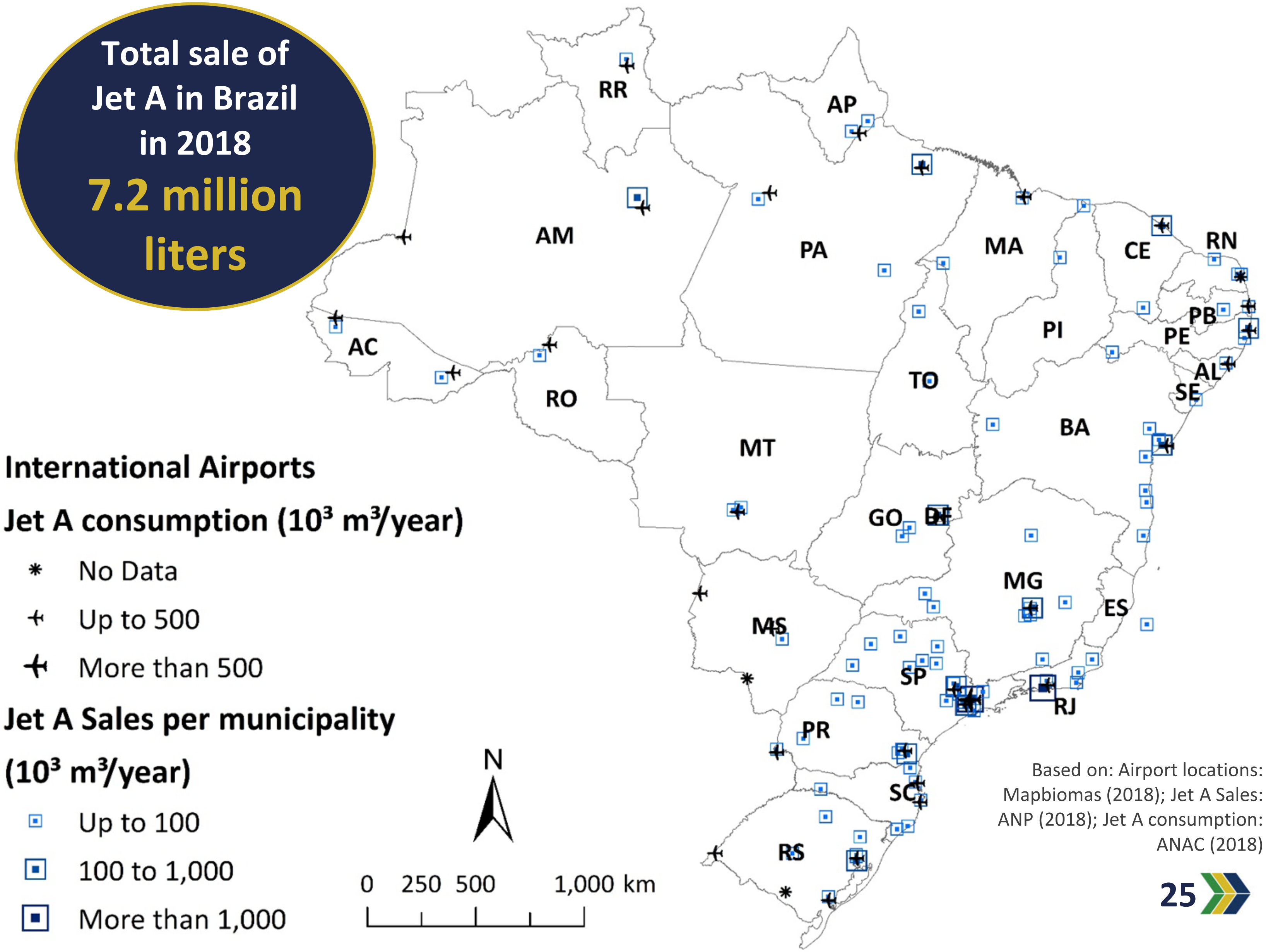
The consumption of Jet A was spatialized according to the fuel sales reported by ANP (2018).

In general, international airports are related to high regional consumption rates.

The **highest consumption** occurs in the **Southeast region**, which also holds the largest numbers of national and international flights. Around **58% of Jet A** sales are destined to SP State and RJ State.

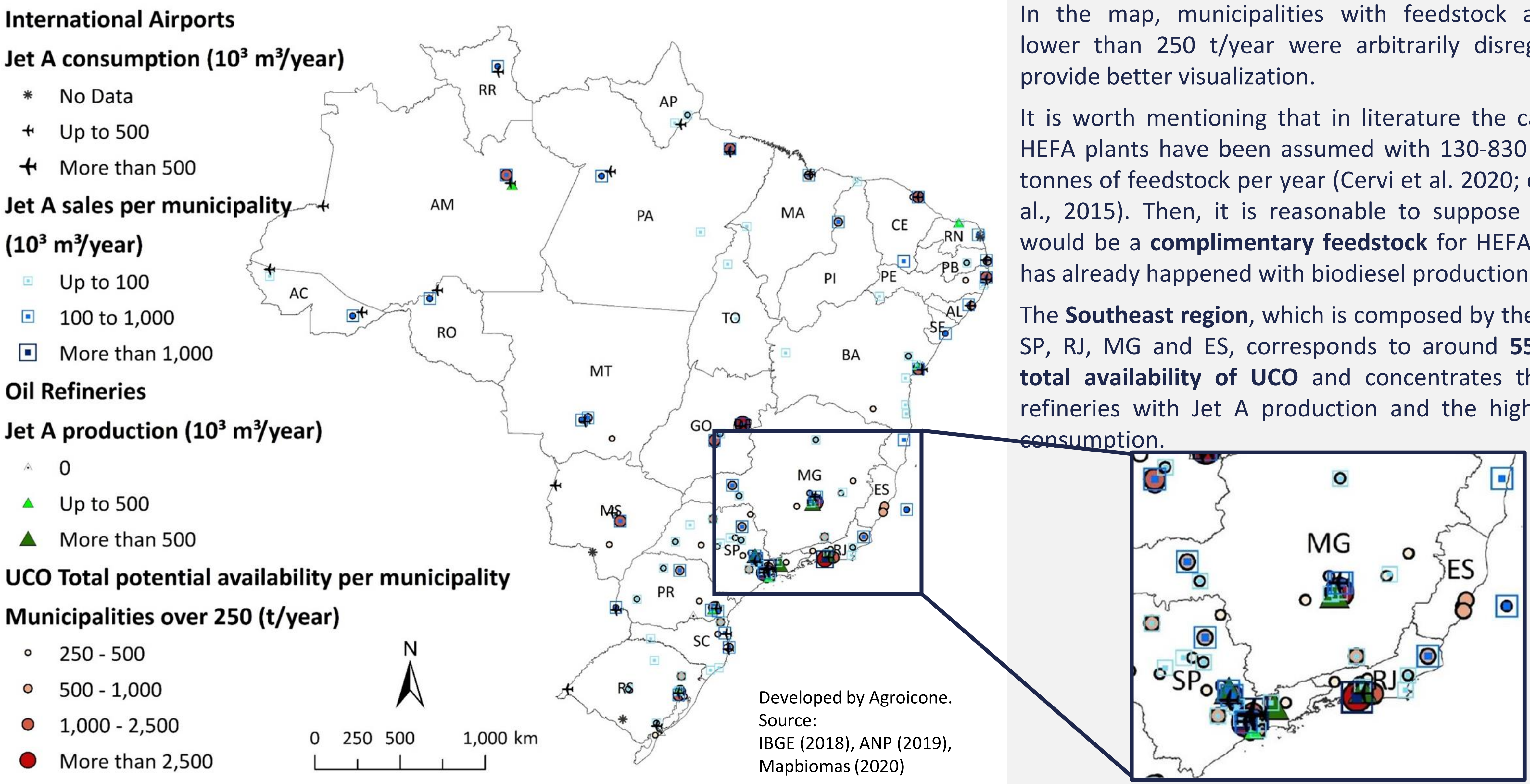
Total sale of Jet A in Brazil in 2018

7.2 million liters



Based on: Airport locations: Mapbiomas (2018); Jet A Sales: ANP (2018); Jet A consumption: ANAC (2018)

MATCHING AVAILABILITY, PROCESSING AND DEMAND



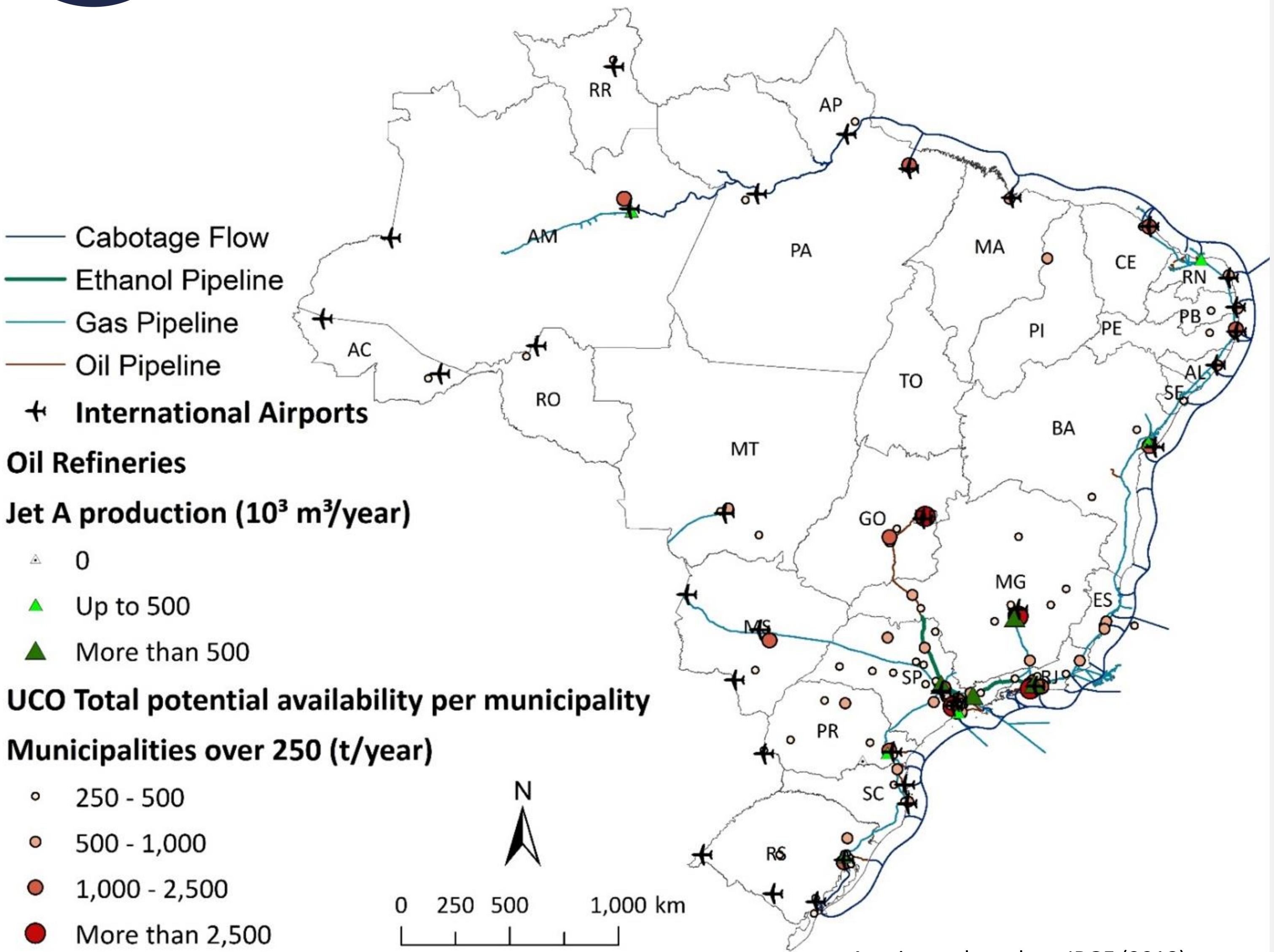
Developed by Agroicone.
Source:
IBGE (2018), ANP (2019), Mapbiomas (2020)

In the map, municipalities with feedstock availability lower than 250 t/year were arbitrarily disregarded to provide better visualization.

It is worth mentioning that in literature the capacity of HEFA plants have been assumed with 130-830 thousand tonnes of feedstock per year (Cervi et al. 2020; de Jong et al., 2015). Then, it is reasonable to suppose that UCO would be a **complimentary feedstock** for HEFA plants as has already happened with biodiesel production.

The **Southeast region**, which is composed by the States of SP, RJ, MG and ES, corresponds to around **55% of the total availability of UCO** and concentrates the largest refineries with Jet A production and the highest Jet A consumption.

LOGISTICS AND INFRASTRUCTURE



Agroicone, based on: IBGE (2018), ANP (2019), Mapbiomas (2020)

Despite the arising interests in the use of UCO, there are still no robust policies or a consolidated supply chain for the collection, storage, and processing of this residue. The collection of the scattered supply of UCO is considered the main bottleneck in order to make its use as a feedstock feasible.

Logistics plans for UCO collection were not evaluated, but it is reasonable to suppose that **medium or big-sized cities** near oil refineries, and through a well-structured collection program would be strategic places for developing this SAF pathway.

The location of gas pipelines are worthy of highlight, considering that they could supply industrial plants for hydrogen production from Steam Methane Reform.

The airports, which are the final consumption sites, and the Harbors and Pipelines are the infrastructure for SAF exportation.

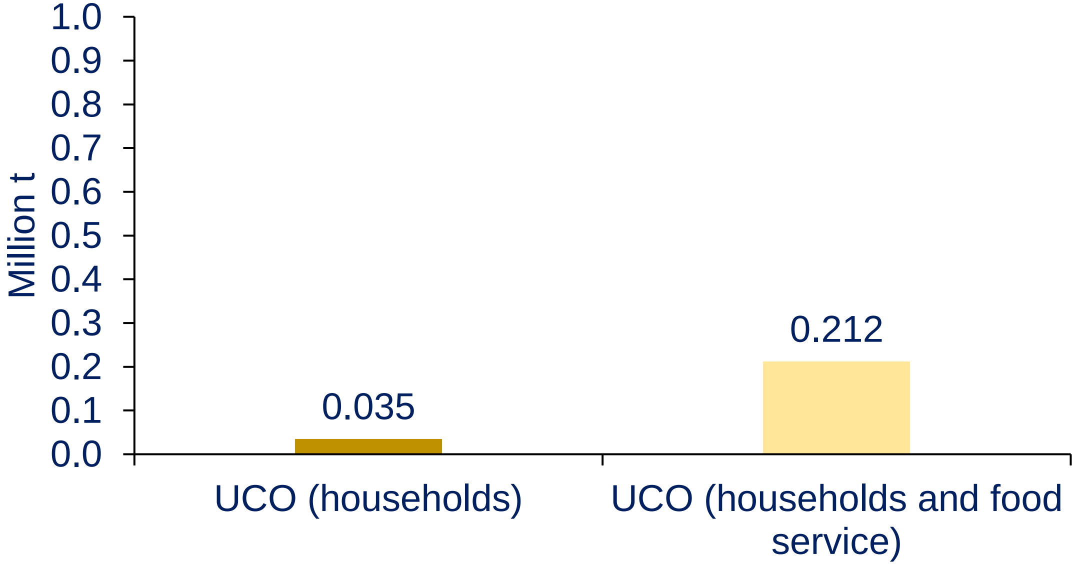
POTENTIAL SAF PRODUCTION FROM UCO

Based on the previous assumptions, the potential amount of UCO ranged from 35 and 211 thousand tons. For the latter, the potential from food services was considered along with that from households. Considering this amount, it would be possible to produce between 18.4 and 111.3 million liters of SAF, which corresponds to **0.3% and 1.5% of the total Jet A consumed in Brazil** in the recent years, respectively.

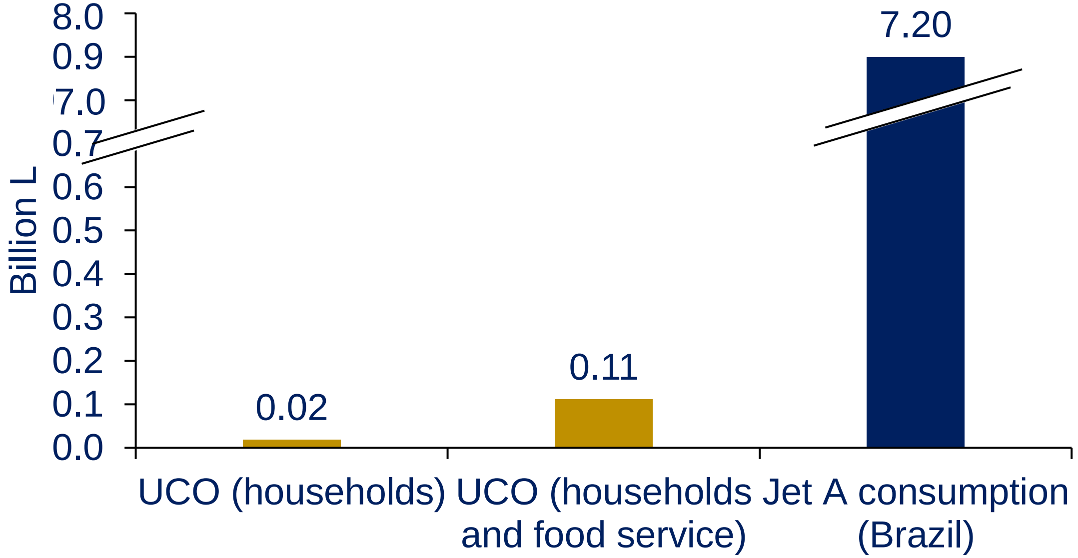
The potential UCO from households is intrinsically related to the collection rate, which was herein assumed to be of 10%, in an optimist context. On the other hand, the potential collectable UCO from food services can vary substantially. Assuming values like those in European countries, when the potential recoverable UCO from food services corresponds to **two-fold** the recoverable UCO from households, the total UCO availability would be of 735 thousand tons, with potential SAF production equivalent to **5.4%** of the total Jet A demand.

It is worth highlighting the increasing use of UCO for biodiesel production, which could become a source of competition in the coming years. In 2019, roughly 75 thousand tonnes of UCO was used by the biodiesel industry (ABIOVE, 2020).

Feedstock availability



Potential SAF production



FINAL REMARKS

KEY MESSAGES

- This project has made significant effort in building a **database** on the availability of UCO for producing SAF, with significant geographical detail on a national level for Brazil. The data will be **available in an online platform** with functionalities to download information for research and within the interest of investors.
- UCO typically comprises the residual oil from frying processes in households or food services, such as restaurants, malls, supermarkets, and the food industry.
- More than 3.0 billion liters of vegetable oil are consumed in Brazil for frying processes. It is estimated that less than **10% is recycled**. Brazil does not have a well-developed supply-chain for the collection of UCO from households and food services. An increasing number of initiatives is observed, motivated by the great opportunity from its lower procurement costs and environmental benefits.
- From 2015-2019, UCO represented, on average 1.2% of the raw materials used for biodiesel production. In 2019, roughly 75 thousand tonnes of UCO were used by the biodiesel industry. The SAF industry could lead to additional competition for this feedstock.
- Based on the consumption of vegetable oils in Brazilian households and considering the potential recoverable UCO from food services in European countries, a total of **35 to 211 thousand tonnes of UCO** could be used to supply between **0.3% and 1.5% of the total Jet A consumed in Brazil**, through HEFA technology.
- The availability of UCO is highly diffuse. **Big-sized cities**, such as São Paulo and Rio de Janeiro, which presented the highest UCO potential, correspond to roughly 10% of the total potential estimated herein. In regional terms, the Southeast region, composed by the States of SP, RJ, MG and ES, corresponds to approximately 55% of the total availability of UCO. This region also concentrates the largest Jet A production refineries and represents more than 70% of the Jet A consumed in Brazil.
- Placing HEFA plants close to oil refineries would be strategic, when considering the demand for hydrogen in the HEFA process, as well as possible integration of the processes. Therefore, big-cities with relevant UCO potential and that are close to oil refineries (and airports) would be strategic places for developing this SAF pathway.

NEXT STEPS

- The project has not performed analysis on issues that deserve to be further investigated, such as:
    - Cost evaluation
    - Life Cycle evaluation
    - Optimization of logistics
    - Integration with other feedstock and with other fuels.

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