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SAFmaps: the WebGIS for sustainability assessment of aviation biofuels in Brazil

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Abstract. *This paper presents the SAFmaps, an open-access WebGIS, that provides a geospatial database about promising feedstocks for the production of Sustainable Aviation Fuels (SAF) in Brazil, and information about their supply chains. The feedstocks addressed are eucalyptus, soybean, palm, macaw palm, sugarcane, corn, beef tallow and steel off-gases. Available information comprises maps of suitability, expected yields and costs for biomasses production, and a set of support maps. Besides maps, the user has access to reports and case studies related to one specific feedstock and region. The paper also presents the main challenges to developing a WebGIS by combining different layers based on a large geographic scope data, using raster layers.*

1. Introduction

The development and commercialization of Sustainable Aviation Fuels (SAF) is the most promising option for reducing greenhouse gas emissions (GHG) emissions in international civil aviation in the short term [ICAO 2021]. The sector aims to reduce net aviation CO_2 emissions by 50% in 2050, compared to 2005 levels [IATA 2021]. A 63% reduction in emissions could be achieved in 2050 if the total international aviation jet fuel demand were replaced by SAF. However, large capital investments and substantial policy support are necessary to achieve high levels of SAF production [ICAO 2021]. Brazil has significant potential for the production of SAFs from renewable crop-based biomasses or residues (e.g., sugarcane, wood, vegetable oils and animal fats) due to edaphoclimatic conditions, land availability and its relevance in biofuels production [Cortez 2014]. In this context, a partnership between the University of Campinas (UNICAMP) and the Boeing-Embraer Joint Research Center for Sustainable Aviation Fuels resulted in the build of the SAFmaps platform.

SAFmaps is an open-access WebGIS that provides easy access to information and data related to feedstocks of interest for the production of SAFs in Brazil, as well as their supply chains. The feedstocks addressed are eucalyptus, soybean, palm, macaw palm, sugarcane, corn, beef tallow and steel off-gases, and the geographic scope corresponds to the areas with the greatest potential for their production. The available geospatial information includes maps of agricultural suitability, expected yields, and estimated costs for different biomasses and existing infrastructure for the sustainable production of biojet fuels, besides a set of support maps that can be accessed at www.safmaps.com. The platform also provides results (e.g., feedstocks supply curves), and reports about case studies developed for each feedstock. The applicability of the SAFmaps database is large and can be also used to guide the production of other bioenergy carriers.

The development of WebGIS has played an important role in providing visualization, access to more users, and analysis of an area of interest [Zhang et al. 2017]. The geospatial information available in the WebGIS environment can be used as a tool of spatial planning and decision support [Khawaja et al. 2021; Esteban and Carrasco 2011]. However, the development of interactive WebGIS systems on biomass given large-scale geospatial data, like Brazil, is challenging. It requires a large computational resource and depending on the type of analysis it may be impractical. The challenges increase given the complexity of simulate biomass supply chains, including the specific characteristics of each crop production, the optimization of biomass logistics, the aim of minimizing production costs and selecting the optimal locations from a sustainability perspective [Pérez et al. 2017; Malladi and Sowlati 2018, de Jong et al. 2017, Khawaja et al. 2021]. Some examples of WebGIS about public database on biomass can be exemplified by BIORAISE (http://bioraise.ciemat.es/Bioraise) and BIOPLAT-EU WebGIS (https://bioplat.eu/webgis-tool) for Europe, and by The Biofuels Atlas (https://maps.nrel.gov/biomass) in the USA context. In Brazil, SAFmaps is an innovative platform with a geospatial publicly available database about several important national biomasses.

This paper aims to present the architecture of SAFmaps WebGIS platform, an open-access platform with a geospatial database about promising feedstocks for the production of SAF in Brazil, which also can be used in different applications in other areas. The paper also presents the main challenges to developing a WebGIS by combining different layers based on a large geographic scope data, using raster layers.

2. SAFmaps platform structure

The SAFmaps provides specific spatialized information for eight feedstocks (that can be used in three routes certified for SAF production), a data set about support maps, reports and the implementation of the results of case studies developed using the information available in the WebGIS platform.

2.1. Geospatial database

The feedstocks addressed include the most promising bioenergy crops in Brazil: eucalyptus, soybean, sugarcane, corn, palm and macaw palm, for which maps of suitability, estimated yields and predicted production costs were developed. The selected geographic scope focus on areas with the greatest potential for their production, and includes the MATOPIBA region (states of Maranhão, Tocantins, Piauí, and Bahia), the Centre–West region (states of Mato Grosso do Sul, Mato Grosso, Goiás, and the

Federal District), the largest area of the Southeast region (states of São Paulo and Minas Gerais), and the South region (states of Rio Grande do Sul, Santa Catarina, and Paraná). The state of Pará was just considered in the case of palm oil production due to the high potential of local production. For the other two non-crop-based biofuels feedstocks, beef tallow and steel off-gases, the platform provides raw availability in 2018 for the whole Brazil, besides general information related to the localization of the associated units (certified slaughterhouses and the main steel mills).

Maps of suitability, estimated yields, and predicted production costs were developed for each crop-based feedstock. The suitability was estimated based on literature information about edaphoclimatic requirements for each culture: soil suitability, rainfall, atmospheric temperature, water deficit, frost risk and altitude. The slopes restrictions to allow the mechanisation of planting and/or harvesting were also considered [Walter et al. 2021a; 2021b; 2021c]. In the final maps, the areas were classified as "low", "medium" and "high" suitability. For all crops, irrigation was not considered aiming to identify areas of lower costs of production and avoiding potential impacts on water resources. To estimate crop yield, statistical regression models were defined between actual yields, edaphoclimatic parameters as explanatory variables and, eventually, a set of dummy variables [Walter et al. 2021a; 2021b; 2021c]. The agricultural production costs were predicted according to the cost structure reported by Agrianual (2020), land prices for pastures in 2018 (assuming that the plantations could only occur displacing pasturelands), and, in specific cases (eucalyptus and macaw palm), it was adopted other parameters of literature for the regional Brazilian conditions. Details about the procedures applied to estimate suitability, yields, and production costs are present in Walter et al. (2021a; 2021b; 2021c). Data were spatialized in raster format (spatial resolution 30x30m) with the software QGIS 3.10. All maps were validated against the information available in Brazil, based on the occurrence of the crops in the literature (e.g., Mapbiomas (2021); IBGE (2021); see details on SAFmaps (2021)). Table 1 summarizes the information available for each feedstock at SAFmaps.

Besides the original data described above, the SAFmaps provides a set of support maps with (i) base information used in the construction of the feedstock maps (i.e., biophysical conditions, land use prices), (ii) data on existing and planned infrastructure (i.e., roads, railways, pipelines, energy conversion units, etc.) and (iii) parameters that can be used to define production restrictions (i.e., environmental and socio-economic restrictions). All support information available in SAFmaps is summarized in Table 2.

Table 1. Information available about feedstocks in SAFmaps

Feedstocks	Information available	Format
Eucalyptus, Soybean, Macaw oil, Palm oil, Sugarcane, Corn (second crop)	Suitability; Expected yield; Expected costs of production	Raster (30x30m)
Tallow	Slaughterhouses certified (SIF); Cattle herd; Beef tallow estimated	Shapefile
Steel off-gases availability	Total of off-gases; Flaring	Shapefile

Table 2. Information available in SAFmaps about support maps

SAFmaps Category	Information
Biophysical	Biomes [1]; Soil orders [2]; Slope categories [3]; Altitude [3]; Average annual rainfall [a,4]; Average annual temperature [a,4]; Average minimum/ maximum annual temperature [a,4]; Annual water deficit [a,4]; IRD (Index of rainfall distribution) [a,4]; Frost risk [a,4]; Main rivers[5]; Hydrographic regions[6]
Diagnostics	Soil suitability [a,7]; Slope - used for eucalyptus [a,2]; Slope - all other crops [a,2]; Level of pasture degradation [8]; Land use and land cover [9]; Land price – Natural pastures [a,10]; Land price – Planted pastures [a,10]
Sensitive areas	Legally protected areas[11-12]; Restricted biomes[1]; CORSIA restriction (Principle 2) [a,9]
Warning areas	Land use rights [a,13]; Water use rights [a, 13]; Agrarian reform settlements[12]
Infrastructure	*Transport:* Roads[14,15]; Railroads[15]; Gas and oil pipelines[15]; Waterways[15]; Airports[15]; Ethanol pipelines [a,15-16]; Ethanol pipelines (terminals) [a,16] *Production Units:* Refineries by aviation kerosene output [a,17]; by oil refining [a,17]; by refining capacity [a,17]; Ethanol distilleries by feedstock [a,17-18]; by sugarcane milling capacity [a]; by anhydrous capacity [a]; by hydrated capacity [a]; by total output [a ,1]; by anhydrous output[1]; by hydrated output [a ,1] Soy processing plants [a ,1]
Political boundaries	Municipalities; States

[a]mapped by SAFmaps (2021) based on information from other sources, some of them non-spatialized.
Sources: [1] https://geoservicos.ibge.gov.br; [2] https://bdiaweb.ibge.gov.br; [3] www.dsr.inpe.br/topodata;
[4] http://dx.doi.org/10.1127/0941-2948/2013/0507; [5] www.ibge.gov.br/geociencia;
[6] https://metadados.snirh.gov.br; [7] Adapted from: (i) Manzatto et al. (2002). Uso agrícola dos solos brasileiros / Rio de Janeiro: Embrapa Solos; (ii) Santos et al. (2018). Sistema brasileiro de classificação de solos. Embrapa, Brasília; [8] www.pastagem.org/atlas/map; [9] www.mapbiomas.org;
[10] www.emater.mg.gov.br, www.agrianual.com.br, www.gov.br/economia; www.gov.br/incra;
[11] http://mapas.mma.gov.br/i3geo; http://sistemas.icmbio.gov.br; www.funai.gov.br;
[12] http://certificacao.incra.gov.br; [13] www.cptnacional.org.br; [14] http://geoftp.ibge.gov.br;
[15] www.gov.br/infraestrutura; [16] www.logum.com.br; [17] www.anp.gov.br; [18] www.conab.gov.br/, www.gov.br/pt-br/orgaos/ministerio-da-agricultura-pecuaria-e-abasteciment, www.novacana.com, www.epe.gov.br/pt.
Details about the source of information can be seen on the platform.

2.2. The architecture behind the SAFmaps

The architecture of the platform allows the recovery of information through the WebGIS application, which was previously compiled using geographic data and the combination of attributes. Figure 1 illustrates the architecture that has been developed with focus on a front-end approach. All the geographic data provided by the WebGIS were processed in advance, respecting simulation rules and requirements regarding the literature. The data were stacked, considering the geographic location of all pixels, which was achieved by the combination of different levels of layers regarding soil suitability, land use and land cover, rainfall and other variables (see sections 2.1 and 2.3).

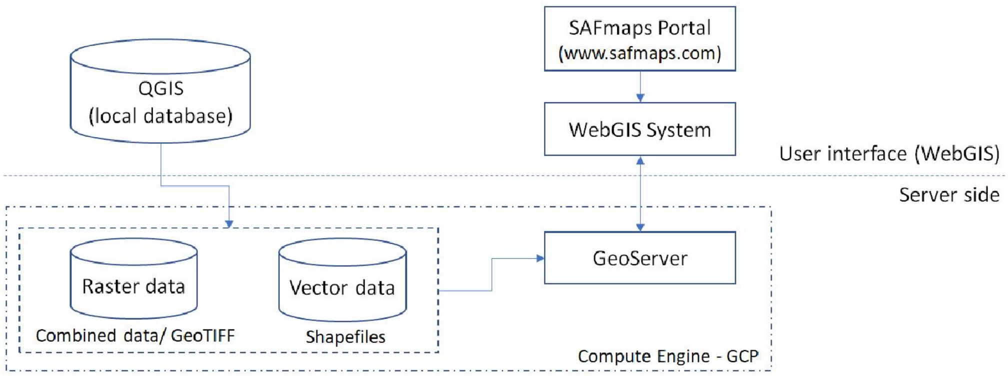

Figure 1. The proposed architecture of the SAFmaps WebGIS system

Some selected data have been incorporated through mechanisms provided by GeoServer and the selection of multiple layers can be performed in the WebGIS application from interface panels. The combination of attributes was performed using GIS like ArcGIS, QGIS, and PostGIS. The results were stored in raster files, mainly due to the geographic scope of the project. Therefore, the maps demanded by users through the WebGIS are selected directly from GeoServer, which retrieves the spatial data from its storage.

The GeoServer uses Web Map Service Interface Standard (WMS) to deliver the data, which provides a simple Hypertext Transfer Protocol (HTTP) interface for the requested map. In the WebGIS, the map is rendered using Leaflet, a Javascript library that displays tiled web maps hosted on a public server with optional tiled overlays. To support this operation, a virtual machine was established in the Google Cloud Platform (GCP), which provides access through GeoServer to the maps consumed by SAFmaps.

2.3. Case studies conception

Several case studies were developed using the dataset available in SAFmaps. The construction and development of the case studies were done in the QGIS 3.10 and ArcGIS 10.1. The site of biomass production, the main parameters and results for each case addressed were statically implemented in the WebGIS system.

The scope of the case studies varied according to the characteristics of production of each feedstock. In general, possible sites of biomass production were chosen based on the area available, expected production costs and the alternatives of transporting feedstock until the SAF production sites. For each biomass feedstock, it was estimated the supply curve at the industrial sites, assuming new processing units in several locations, considering different biojet fuel production capacities.

The production areas were defined as a circle around a point selected for the location of the processing industrial unit. It was assumed that crops could be cultivated only over pasturelands (in 2018, according to land use maps presented by Mapbiomas (2020), spatial resolution 30m x 30m). For the areas of potential cultivation, it were excluded protected areas (i.e., conservation units, indigenous reserves and quilombolas), two sensitive biomes (Amazon and Pantanal), the areas in non-eligible lands according to CORSIA's sustainability criteria [CORSIA 2019], and regions where potential socio-economic problems would be predicted (e.g., due to violations of land and water use rights).

Aiming to allow full mechanization, the pixels were filtered to identify clusters with a contiguous area capable of producing at a low cost. For this, the Landscape Ecology Statistics (LecoS) plugin for QGIS was applied to clean small pixels in the agriculture area [Jung 2016].

Information for each feedstock was combined with existing and planned infrastructure data aiming to reduce transport costs according to the available alternatives. The procedure to estimate the distance from the field (pixel) to the processing industrial unit (point) was based on a combination between the *Arcgis Network analyst* extension and the tool *Proximity (Raster Distances)* of QGIS. The transportation cost, by truck, was calculated based on the field-unit distance using the *Raster Calculator*. Due to the required infrastructure, it was supposed that SAF production may be at or very close to large oil refineries, and near to the main consumers of aviation fuel (i.e., international airports). In this case, transportation costs between unit-refineries were estimated exploring alternatives to roads, such as pipelines (for ethanol) and rails.

The procedure to define the supply curve at the industrial unit was obtained by a layer stacking process combining the cost of production and the estimated yields by pixel. Based on the size of the pixel, it was estimated the area available for feedstock production. From the stack, it was possible to know the potential of crop production in each pixel (according to the yield values) and its respective cost of production. In PostGIS these values were retrieved using SQL queries. The costs of transportation unit-refinery and industrial process were added to the costs of feedstocks production. The production areas were ranked from minimum to maximum costs and the supply curve was traced. The feasibility of SAF production was assessed based on its minimum selling price (MSP).

3. SAFmaps portal and platform

SAFmaps is composed of a Portal which provides information about the project and partnerships (tag Home and About/SAFmaps), a set of links to important pages in the context of sustainable aviation fuels (About/Useful links), and a list of publications related to the development of the project (About/Publications). The tag Database gives access to the WebGIS with maps, reports and case studies.

3.1 SAFmaps layout

The layout of SAFmaps is shown in Figure 2. Accessing the Database (Figure 2), the user is directed to the Support maps (Figure 2b), and a set of specific information about each feedstock (Figure 2c). For each feedstock, the user can combine information about the suitability, costs, and yield with infrastructure data (e.g., main roads, railroads, pipelines, airports, energy conversion units, etc.)

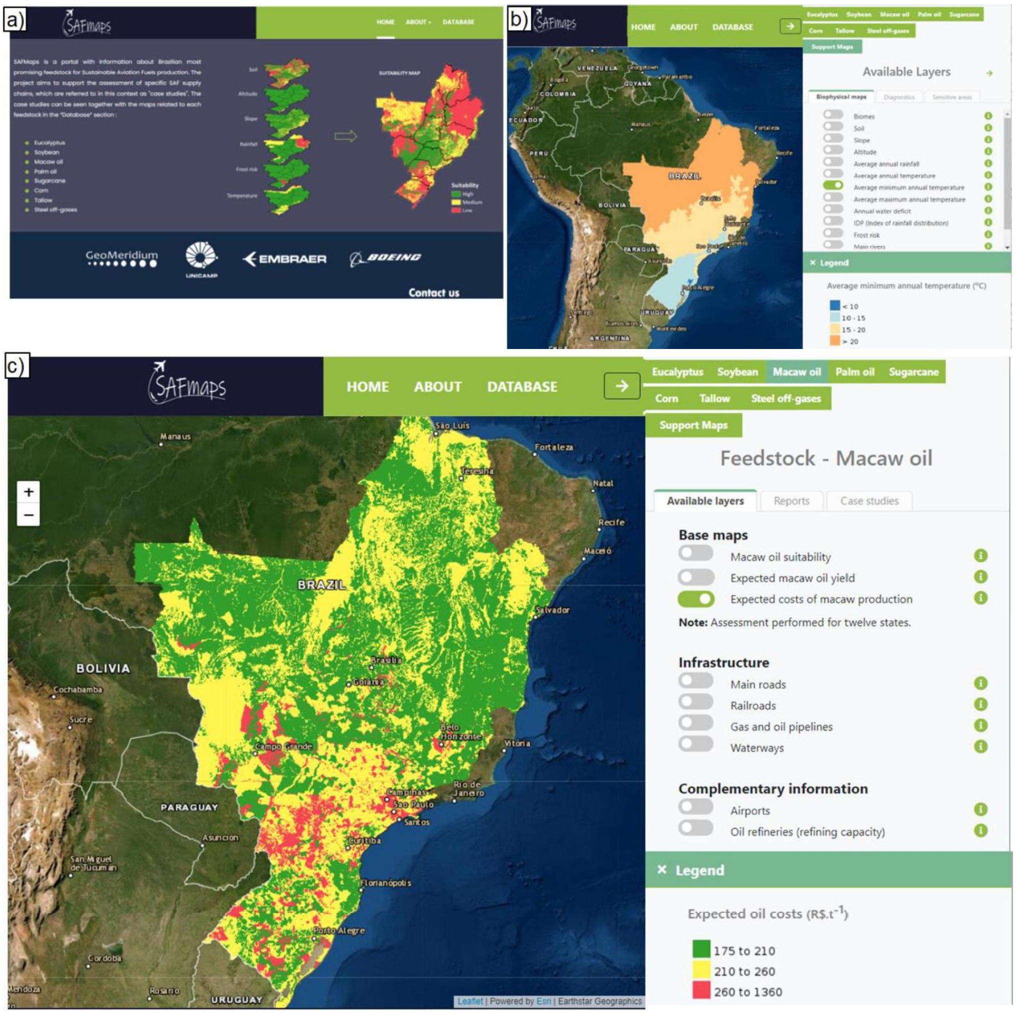

Figure 2. a) Platform SAFmaps (WebGIS access through the tag Database; b) Example of maps in the tag Support Maps, c) Example of feedstock information.

The case studies implemented illustrate the application of the information available in the SAFmaps database to evaluate the potential of SAF production in Brazil. Figure 3 exemplifies the steps and parameters requested for the user. In Step 1 (Figure 3a), it is required the selection of the conversion technology to SAF, the feedstock (in some cases, there is a combination of different crops) and the available map that the user wants to see. In Step 2 (Figure 3b), it is presented the options of integration strategies related to the location of the industrial unit simulated in the case study. According to the industrial capacity selected, the platform calculates and returns the industrial production of SAF (input requirement) and the co-products output from SAF production (diesel, naphtha, electricity).

The results also show the supply curve of SAF production in the industrial site, based on the available areas for crop production inside the selected zone. As can be seen in Figure 3c, a set of additional information such as feedstock requirement, average weighted costs and minimum selling prices (MSP) of SAF for the selected route is also presented as tables.

For each map, it was implemented an information icon that describes how data were obtained and also provides the links to download the database, or directs the user to the page of original source of information.

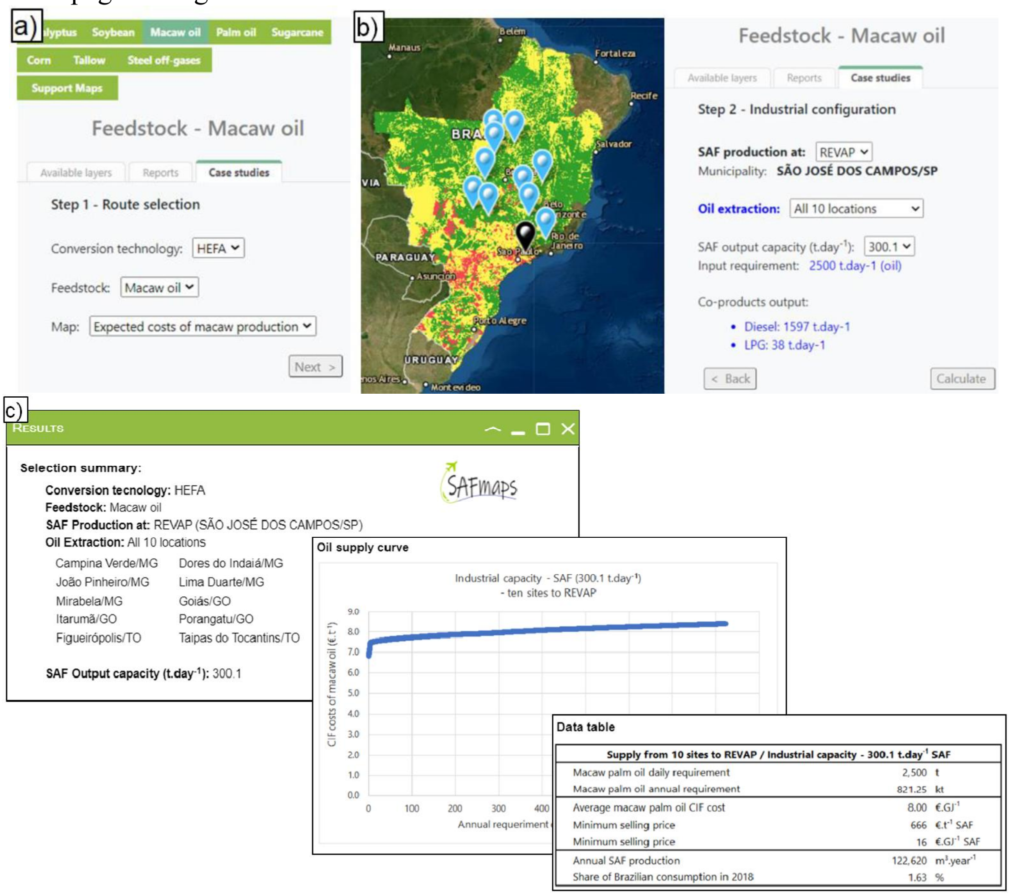

Figure 3. a) Step 1 - Route of SAF production and the map chosen by the user, b) Set of the parameters of configuration, and results of co-product output; c) results of case studies implemented in the SAFmaps: feedstock supply curve and other information related to the case chosen by the user.

3.2 Database download

The geodatabase of SAFmaps was stored on GCP and made available through Geoserver. However, the set of georeferenced/tabulated data and reports have been stored in the Mendeley Data, which aims to facilitate the dissemination of data in the scientific community, the organization of available data and the monitoring of accesses to the database. The information can be accessed through the links detailed in Table 3. In ten months, the statistics point to almost 1170 views and 360 downloads.

Table 3. Links for download dataset

Information	Title of dataset	DOI - Mendeley
Feedstock	SAFmaps – Eucalyptus	http://dx.doi.org/10.17632/ghvrstw7pw
	SAFmaps – Soybean	http://dx.doi.org/10.17632/jpwggmp9zy
	SAFmaps – Macaw palm	http://dx.doi.org/10.17632/5498jdrm87
	SAFmaps – Palm oil	http://dx.doi.org/10.17632/t59v47sshp
	SAFmaps – Sugarcane	http://dx.doi.org/10.17632/dp4y36fjw5
	SAFmaps – Corn	http://dx.doi.org/10.17632/g25wt3t7k5
	SAFmaps – Beef tallow	http://dx.doi.org/10.17632/2zc8p9dgg9
	SAFmaps – Steel off-gases	http://dx.doi.org/10.17632/nj7f67k8vv
Support maps	SAFmaps – Diagnostics	http://dx.doi.org/10.17632/czrwfbd7ct
	SAFmaps – Infrastructure	http://dx.doi.org/10.17632/kwdd5mbg4h

4. Discussion and main challenges

One of the main challenges of SAFmaps developers is to make the platform more flexible for the users. Thereby, it would be helpful to include online simulations based on the user requirements , expanding its functionality as a tool of spatial planning and decision support for the civil aviation sector. However, two main difficulties should be overcome: (i) the complexity of implementing biomass supply chain for large-scale biofuels production, until the obtaining of a feedstock supply curve, online, using several geospatial data, and (ii) the processing of data on the fly, considering the selected areas by users in the WebGIS and its potential large geographic scale.

A typical biomass supply chain system includes the sites of feedstock production, storage and preprocessing facilities, biorefineries, truck transportation farm-facilities (in the case of SAF, also facilities), besides integration of agriculture suitability, technology development, economic, and environmental considerations [Malladi and Sowlati 2018, Lin et al. 2015]. Most models of biomass supply chain optimization are not web-based. In general, existing models require the combination of several rules and levels of data, which demand significant computational resources of processing power and memory, especially to solve wide geographic coverage. Some options include mixed-integer linear programming, spatial decision support platforms, and tasks of optimization modeling, not limited to a single user and small-scale problems [Hu et al. 2017, Lin et al. 2015].

Processing multiple raster layers simultaneously, for a large-scale georeferenced and with several levels of data requires modern approaches, demands the ability to combine and stack data. In general, the development of such systems implies the construction of environments with pre-aggregated data processed in conventional GIS, as a step before loading them to the WebGIS system [Zhang et al. 2017]. A promising alternative that can help to address this issue is the concept of Data Cube, which uses a set of specialized technologies to solve problems with large volumes of data of Earth

Observation (EO) [Giuliani et al. 2020]. This concept has been used in many projects, such as Google Earth Engine (GEE) [Gorelick et al. 2017], and Brazil Data Cube (BDC) Platform [Ferreira et al. 2020], where raster layers are assembled into multidimensional data cubes [Gomes et al. 2021]. Open Data Cube (ODC) technology is focused on data processing and analysis using Python packages and command-line tools that can use Databases Management System (DBMS) like PostgreSQL to store metadata for managed data [Gomes et al. 2021].

In the case of SAFmaps, the combination of spatial data was accomplished by stacking them in several small local cubes, and as in a raster image, each layer was represented by a band. Information from costs, yields, land use and land cover mapping in raster images, for example, was overlaid in several layers. Thereby, in the data stack, the values for each band were obtained by selecting geographic coordinates represented by a pixel or a set of pixels. Nevertheless, this solution was achieved for small areas in predetermined locations, according to its agricultural vocation and pasture availability. The result set of each location was saved in self-contained raster files with both yield and cost levels of information from which the supply curve was acquired and estimated. The data were provided by the platform according to the architecture presented in item 2.2 and the maintenance of the system can be performed through the virtual machine in GCP where the GeoServer is hosted, by replacing the raster data. In future cycles of development, an infrastructure shall be established to support online users requests, triggering responses within an acceptable timeframe to allow real-time creation of supply curves and other essential comparisons for the decision-makers regarding the production of biomasses.

SAFmaps platform provides aid tools for potential investors in sustainable biojet production, as well as public policymakers. Database can be used to develop research scenarios of SAF production, based on the agricultural, technical, economic feasibility of several promising feedstocks, indicating potential solutions with lower environmental and social risks. In order to contribute to reducing GHG emissions, SAFmaps database gives a set of information that indicate alternatives to crop production in areas of low iLUC (induced land use change) risk, e.g. in degraded pasture areas, and potential production areas that are in accord to the principle 2 of CORSIA's sustainability criteria. In addition, raw biojet transportation alternatives of low energy intensity can be combined to reduce costs and GHG emissions, as exemplified by the seven case studies available on the platform.

6. Conclusions

The SAFmaps provides easy access to a set of maps, geospatial database, results of case studies and reports related to feedstocks of interest for the production of sustainable aviation fuels (SAF) in Brazil. The innovative platform can be used as a tool for potential investors in SAF production, public policymakers, the civil aviation sector itself, researchers and general users. Information also can be used to assess the sustainable production of bioenergy in different applications.

The complexity of implementing the biomass supply chain for large-scale biofuels production and the processing of data on the fly are some of the challenges of the development of the WebGIS system on large-scale geospatial data. Under these conditions, the simultaneous processing of multiple raster layers requires the combination and stacking of data. The Data Cube concept can be used in future versions of the platform to allow users to analyze in real-time a large number of options, including different biomasses, different production sites and possible transport options.

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