POLITECNICO DI TORINO

Master of Science in Environmental Engineering

Natural Risk and Civil Protection

Master thesis

A step forward toward the high-resolution assessment of water footprint at the company's scale

Supervisor:

Prof. Francesco Laio

Co-supervisor:

Prof. Marta Tuninetti

Candidate:

Elena De Petrillo

s265557

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Chapter 1

Introduction

In occasion of the World Water Day 2018, the United Nations launched the International Decade *"Water for Sustainable Development"* to accelerate efforts towards meeting water-related challenges. Though, on the 15th February 202, the president of the UN General Assembly Volkan Bozkir reports in his Concept Note that:

> "The world is currently off-track to meeting the targets of SDG 6".

At the same time, the global society is pressed by an increasing food demand, making the food system a key driver of water depletion, both directly, through the over exploitation of water resources, with withdrawals from surface water bodies and aquifers, and indirectly through deforestation, biodiversity loss, pollution and climate change alterations which overall modify the hydrological cycle and the water availability worldwide. The United Nations World Water Development Report 2020 Water (2020), focused on water and climate change, reports that the degradation of ecosystems will not only lead to biodiversity loss, but will also affect the provision of water-related ecosystem services Water (2020). Also, there is increased competition for land, water, energy, and other inputs into food production altogether, calling for a better integrated assessment and management of the food system. There is though an urgent need that these scientific assessments get involved in countries' supply-policies, especially to accomplish the United Nations targets related to the Sustainable Development Goals and the Agenda 2030. In the Concept Note, Volkan Bozkir specifies:

> "Member States need support to strengthen their ability to comprehensively review and accelerate progress towards meeting the global water-related goals. With only 10 years to go to achieve the SDGs, we need an immediate and integrated global response to rapidly improve progress on SDG 6. The United Nations, Governments and key stakeholders are fully behind the SDG 6 Global Acceleration Framework which was launched during the High Level Political Forum in July 2020. This Framework is galvanizing the international

community's support around five key accelerators: financing, data and information, innovation, governance, and capacity development."

This scenario suggests that the water assessments of the globalized food production should in a first place enhance a multi-variables approach, considering in an unique framework the major environmental and social drivers involved and then connecting consumer countries and stakeholders, both retailers and producers, to enhance the effectiveness of supply-chain policies and meeting global sustainable targets, as suggested in Godar et al. (2016). The present thesis aims at proposing a methodology where the water footprint assessment at the local scale of production is related to other major environmental and socio-economic features of production, and at providing data-information for policy actions and stakeholders management through connecting the site specific water assessment to the retailing path of the consumer supply-chain, focusing on the virtual water flow assessment of the Brazilian soybean imported to Italy in 2018.

Figure 1.0.1: Copernicus Sentinel-2A satellite surveying land use change in central-eastern Brazil, image captured on 8 August 2016.

Figure 1.0.1 provided by Sentinel 2-A depicts the land use-change that Brazil has been facing since the first years of the 2000s as a consequence of soybean production. Specifically, the satellite image was captured above the Eastern region of Brazil that recently started facing water resources depletion and water conflicts (Pousa et al., 2019).

On the one hand, Brazil is one of the richest biodiversity countries in the world with six unique biomes: Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal. These biomes have the largest global reserves of freshwater and consist of large carbon stocks in their forest and soils (Souza et al., 2020). On the other hand, this country is one of the world's top producers of agricultural commodities and, above all, is the global frontier of soybean production. In 2019 the Brazilian soybean production accounted for 114 million tonnes harvested over almost 36 million hectares, 360'000 km^2, an area greater than the Italian territory, equal to 302'073 km^2 .

Also, the average farm size typical of the Brazilian agriculture is one of the largest in the world (Samberg et al., 2016), thus underpinning a small contribution of the small-farm agriculture (Ricciardi et al., 2018). In 2000, Brazil was identified as being the cropland reserve of the world, along with Tropical Africa, when "new" harvested land were just beginning to be exploited. However, Ramankutty et al. evidenced already that tropical soils will have lose fertility rapidly once the forest cover would have been replaced by cropland, hence requiring expensive inputs to maintain the soil nutrients and conserve the soil organic matter. Nowadays, Brazil is the first producer of soybean worldwide, followed by the US - detached with a variation of 15%- its production since 2015 toward China has grown remarkably. Figure 1.0.2 points out the exponential trend of soybean water footprint volume over time (Tamea et al., 2020), driven by an exponentially increasing production.

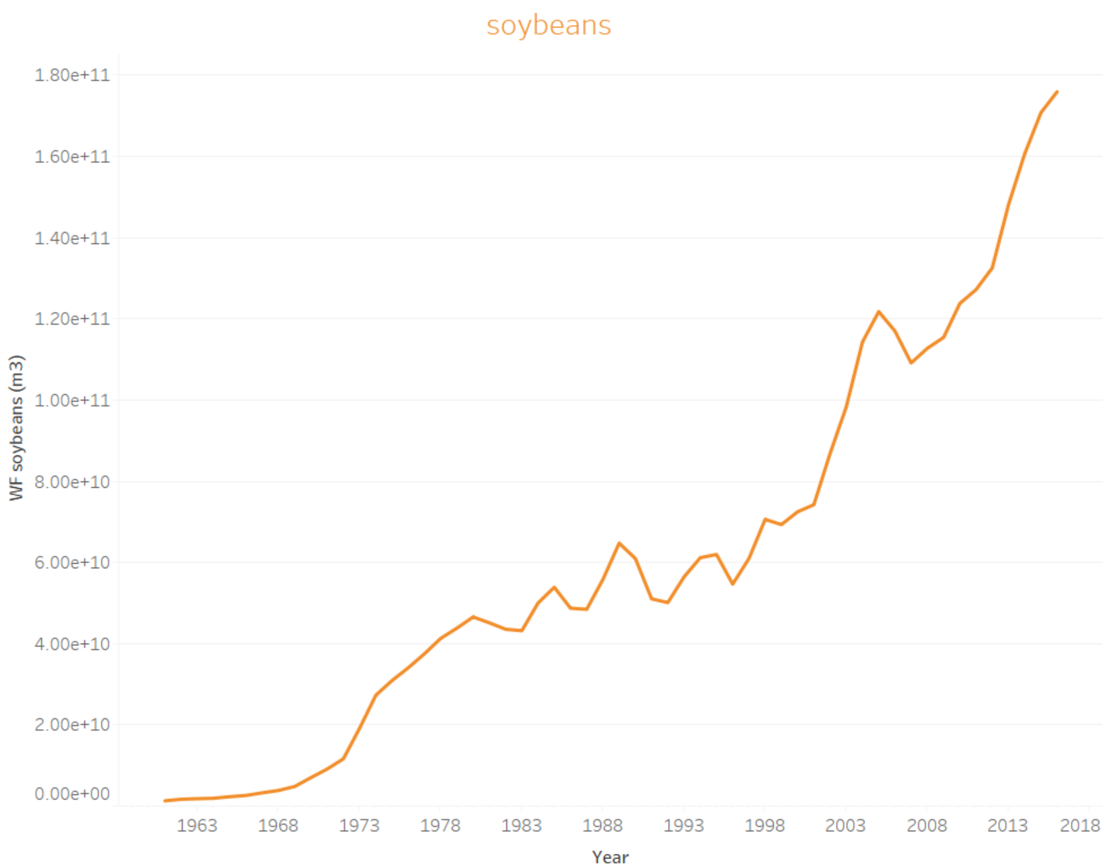

Figure 1.0.2: Brazilian soybean production production over time, CWASI database: 1961-2016 (Tamea et al., 2020)

Also, soybean harvest is run in different part of the Brazilian country, of extended dimensions and of countless ecological and social peculiarities. Indeed, Brazil extension is twice the size of the

European Union territory, (8.5 million km^2 versus 4.32 km^2) though it tends to seem less extended on the Mercator word map, the common planispher, due to areal deformations of representation. In fact, the Mercator projection enlarges the size of countries nearer to the poles (US, Russia, Europe), while downplays the size of those near the equator (Africa, South America). The tool The True size provides a quick areal conversion and countries true size overlapping on the planispher, allowing to clearly catch the real dimensions of the lands interested in this study, as in figure 1.0.3.

Figure 1.0.3: True size of Brazil over Europe, The True size

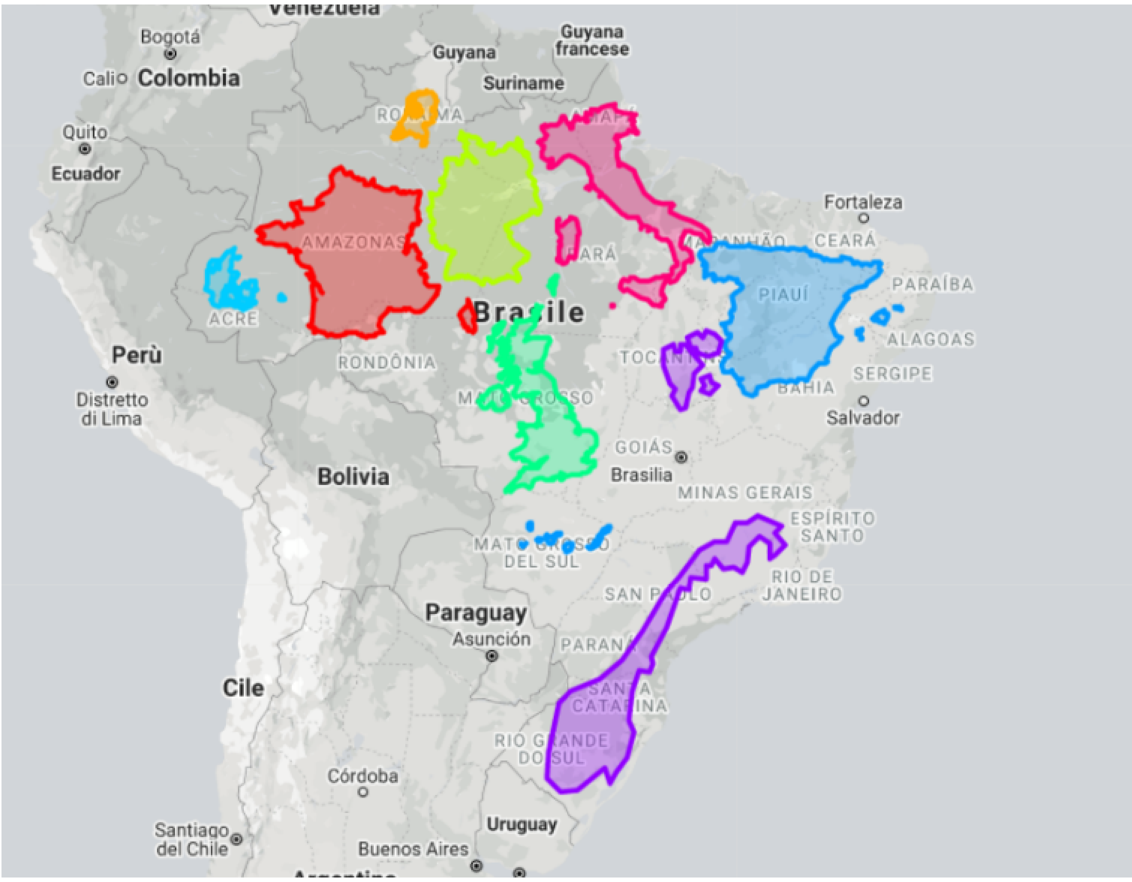

Figure 1.0.4: European main soybean importers overlapped on Brazil in thei true size, The True size

The role of European country in driving the supply demand of soybean is emphasized by some agreements, such as the Amsterdam Declarations, (Trase, 2018a), which commit to fulfill deforestation-risk supply chain. The key purpose of this study is to build supply matrices engaging multi-environmental impacts indicator shaped and contextualized for a specific supply-chain commodity - the Brazilian soybean in this case- and importer country aiming at setting the base for free-water risk supply-chain assessments, related to the other environmental impact indicators. Also, the matrix carries within information about the trader companies, which impact assessment follows the one at the sub-national scale and directly connects the production to the consumer country. The study is mainly funded on the new methodologies of supply-chain analysis, as the model provided in Trase proposed by Godar et al. (2015), water footprint resolute database from (Tuninetti et al., 2015), virtual water trade (VWT) volumes of reference set by CWASI database for the period 1961-2016 (Tamea et al., 2020) and FAOSTAT statistics on country scale food production and trade.

The current VWT assessment (Aldaya et al., 2012) (Mekonnen and Hoekstra, 2011) (Tamea et al., 2020) tipically rely on water footprint volumes at the country scale. Thus, even though the spatial resolution and accuracy of water footprint improved over time in the literature, both in terms of spatial and temporal variability (Tuninetti et al., 2015), (Tuninetti et al., 2017) this high resolution is generally lost in virtual flow assessments, which aggregate the gridded water footprint values with trade data at national scale (Flach et al., 2016). Moreover, Gardner et al. (2019) indicates the scale of the assessment as the first factor to be crucial in order to improve the supply chain sustainability governance. This thesis aims at proposing a methodology to bridge the gap between the high resolution scale of the hydrological modeling of water footprint and the scale of international virtual water flows assessment. To give relevance to the influence of local heterogeneity on environmental footprints, as supported by Croft et al. (2018), this study focuses on the sub-national scale of trade flows, and on the investigation of the final consumer supply-chain in order to link the importer country and its consumption patterns to the local production and its impacts. Recent leading improvements in supply-chain mapping, marked by Godar et al. (2015) releases high resolute data of trade and production between the producer localities and the importer country. This study proposes a detailed virtual water trade assessment at a high spatial resolution of the imported Brazilian soybean in the Italian supply-chain.

The thesis is organized in the following chapters: chapter chapter 2 presents the multiple sets of data used for the water footprint. Then, chapter chapter 3 proposes the methodology introduced to assess the water footprint of production and the high-resolution virtual water flows. The first section of the methodology focuses on the elaboration of the model proposed by Godar et al. and on its merging with the water footprint data, in order to assess the impact of production at the sub-national scale. Other environmental features, such as the anthropogenic biomes (Ellis and Ramankutty, 2008) and the support of satellite land surveys of European Space Agency, are introduced in the assessment. The second section is focused on the evaluation and analysis of the major trader companies' involved in the soybean exports toward the Italian country. Their water-efficiency and geographical distribution over the Brazilian territory are analyzed and discussed. The last section assesses the Italian supply chain and allocates the water footprint volumes at the company's scale in the domestic utilization features through FAOSTAT bank data. Results are shown, interpreted and discussed in chapter 4. chapter 5 provides a focus on the current Italian soybean yield gap and the potential climatic yields, as revealed by Licker et al. (2010), in order to present a possible solution to slow down soybean production in Brazil. Finally, in chapter 6 the conclusions highlight the importance of sub-national virtual water trade assessment, both at the scale of production and at the scale of consumption in valuing the heterogeneity of the water footprint at the local scale in the virtual water assessment at a national level. As well, they are illustrated the opportunities and the future possible improvements of:

- enhancing the spatially resolute agricultural and climatic databases with the recent methodology of supply-chain mapping.;

- deepen the domestic supply unbundling.

Appendix A is dedicated to some calculated intermediate outputs for the Italian import. In Appendix B, Appendix C, Appendix D, Appendix E, Appendix F, Appendix G are reported for each major trader company analyzed, the localities engaged in their sourcing production, their water-efficiency and yield cumulated frequency curves over their run production. In Appendix H are reported the results obtained through the elaboration of the trade data at the sub-national scale for the other main european importers: Spain, Netherlands, France, Germany, United Kingdom, Denmark and Norway.

Chapter 2

Data

As illustrated in chapter 1, the scale of the study is a pivotal point of the present thesis. The high spatial resolution of production at sub-national scale has been sourced from Trase, a partnership between the Stockholm Environmental Institute, SEI, and Global Canopy. Trase aims at tracking with the highest transparency the supply chains of commodities exposed to deforestation risk. Currently, the commodities traced are thirteen: soybean, coffee, beef, sugarcane, cotton, shrimp, cocoa, palm oil, palm kernel, chicken, pork, wood pulp, corn, in the countries of: Brazil, Paraguay, Argentina, Peru, Ecuador, Indonesia, Bolivia, Colombia, Ivory Coast and Ghana. In this sudy the focus has been posed on Brazilian soybean, for the reason discussed in chapter 1. Thus, the identification of the players of export and import provided by Trase for the Brazilian soybean worldwide, has turned fundamental for disaggregating the virtual water flow from the local municipality to the final consumer.
Specifically, Trase data on supply-chain dynamics serve this study in detecting:
1. the sourcing municipalities, in order to obtain the sub-national spatial resolution of production;
2. the companies handling the export and involved at the local scale in order to connect importer's consumes with the local impacts.

Trase database is merged with water footprint data ($m^3/tonnes$) at 5 minutes arc resolution, calculated by Tuninetti et al. (2015). The same grid resolution belongs to the crops yield ($tonnes/ha$) and production ($tonnes$) mapping worldwide of Monfreda et al. referred to the year 2000. Other information available at the sub-national scale, to be merged with Trase data on production for the year 2018, are the anthropogenic biomes mapped by Ellis and Ramankutty (2008), with a spatial resolution of 5 arc minutes. Related to the study of Monfreda et al. is also the climatic potential yield estimation of Foley et al., available worldwide at 5 arc min spatial resolution.
At the national scale, water footprint and virtual water trade values refer to CWASI database,

Tamea et al. (2020), grounded on Tuninetti et al. (2015) andFAOSTAT data. The updated and new Food Balance Sheet, FBS, by FAOSTAT (b), are the sourcing data for the second part of supply-chain analysis along with the Production and Trade sheets, FAOSTAT (a), FAOSTAT (c). The Italian Food Balance Sheet for primary soybean provides data about the entire supply and utilization patterns. The new version of the FBS has been released at the end of January 2021. These new data rely on an innovative imputation methodology to fill the gap of missing data. For geographic representation and spatial analysis the have been sourced from Brazilian administrative web portal the administrative, hydrological and geograpphic shapefiles or tabular information available of Brazil, IBGE. Data have been downloaded also from OCHA. Italian national statistics and administrative boundaries have been sourced by ISTAT.

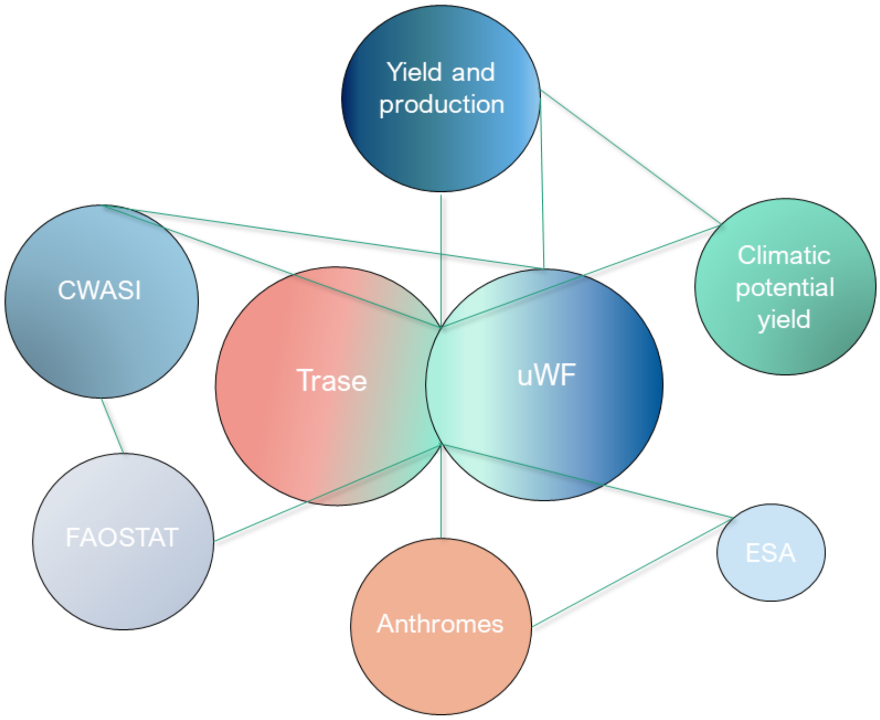

Figure 2.0.1: Venn Diagram for data

2.1 Sub-national trade flows: the Trase database

Sub-national supply chain data at the scale of production are useful tools to identify the sourcing locations and to trace the export flows knowing the players of export and import- the trader companies. Open data are available for download at Trase . The work of Trase is fundamental in order to identify the Brazilian local spots of production and the stakeholders involved in the export of the soybean produced at the scale of municipality in order to connect the local impact of soy production to the importer supply. The stakeholders at study are the soy traders, companies that buy soy from farmers or processors, transport it and sell it to manufacturing companies around the world Trase. The Trase database provides data as a matrix of trade data where municipalities are related to exporter hubs, export trader, importer country - or domestic consumption-, importer trader. Trade data are obtained through customs records and maritime shipping contracts, tax registration data, logistic ownership and capacity, sanitary and commodity movement controls, and production data (Godar et al., 2015). The supply-chain detection of Trase relies on the *Spatial Explicit Information on Production to Consumption Systems* (SEI-PCS) method, first introduced by Godar et al. (2015). This approach provides a methodology for mapping sub-national supply chains which is adapted to suit different country and commodity contexts. Depending on data availability and methodological improvements, a given country-commodity combination is mapped using different SEI-PCS versions. In the case of soybean trade, the version available is the most updated, the 2.3, released in December 2018. This version is expected to be stable, with only minor improvements planned (v.2.3.1) – for example when new data become available that can reduce the volume of unknown flows, or revise the name of trading companies following mergers and acquisitions (Trase, 2018c).

The first release of SEI-PCS for Brazilian soy from 2010 to 2015 was released the 11 November 2016. It used detailed per-shipment customs data to identify state of production for each shipment, and multiple independent data sets to identify soy logistical hubs (storage, crushing facilities), including detailed self-declarations from corporate websites and sustainability reports. Production municipalities are connected to logistic hubs within predetermined soy-sheds based on levels of production. Version 2.2, accounting for soybean trade between 2010 and 2015, was released the 20 September 2017. It linked per-shipment information from customs data to localities of production and logistics facilities based on common asset-level tax registration numbers. Hard-to obtain self-declarations were removed. The 2.3 version accounts for Brazilian soy trade from 2003 to 2017. It works as the same as v.2.2 but with significant improvements in the accuracy with which the sourcing regions of individual shipments are mapped, due in particular to mapping of domestic demand centres, improved data coverage and the inclusion of official records of assets per trader, activity and municipality Trase (2018c). In particular, for the purpose of this study, the best improvements of version 2.3 are:

- The inclusion of accurate assessment of domestic demand and processing facilities. The domestic demand consists basically in production of feed for livestock or biofuel. The centres of domestic demand compete in this version in determining the sourcing patterns of soybean along with exporting hubs. Thus, the allocation of soy trade at the municipality scale in version 2.3 depends on both its geographical location and the distribution of domestic demand within the country. The mapping of all crushing facilities in Brazil has also allowed to more accurately link cake and oil exports with specific logistic hubs, allowing to decrease the total volume of cake and oil exports classified with an unknown origin;

- The conversion factors to commodity equivalent turning on weight- based approach and not on caloric coefficients;
- The introduction of a weight-of-evidence approach to determine sub-national sourcing of soy exported from the state of Sao Paulo where there are a lot of wholesale and retail facilities of trading companies that are far removed from areas of production. As a result, most of the remaining “unknown origin” volume in SEI-PCS 2.3 for Brazilian soy is related to the state of Sao Paulo.

These insights will be explored for the Italian case in chapter chapter 3 and chapter 4.

2.2 Sub-national crop water footprint

The crop water footprint ($m^3/tonnes$) quantifies the water content of a crop production. Its spatial variability, through its dependency on climate and crop yields, is mapped worldwide, at the resolute scale of 5×5 arc min, corresponding to pixels of about $9\,km \times 9km$ at the equator, in the work of Tuninetti et al. (2015). In each pixel it is defined as the ratio between the water evapotranspired by the crop during the growing seasons of a year y, $ET_{a;y}$ (mm), and the crop actual yield, Y_a $(tonnes/ha)$:

$$uWF = 10 \cdot \frac{ET_{a,y}}{Y_a} \qquad \left(\frac{m^3}{tonnes}\right) \tag{2.2.1}$$

where the factor 10 converts the evapotranspired water height expressed in mm into a water volume per land surface expressed in m^3/ha. The estimates are referred to the time interval from 1996 to 2005: a data range of 10 years which makes the input data independent of inter-annual fluctuations and typical of each grid cell. The reference period is centered on year 2000 because this is the most frequent reference year in the global agricultural data sets used in the study (e.g.crop calendar, crop yields, and harvested areas). The work relies on resolute map of soil water available content given by FAO and the 10 arc min maps of monthly precipitation given by New et al., 2012 and it accounts for the existence of multiple growing seasons as in Siebert and Doll, 2010. In regions where more than one crop per year is planted and harvested (i.e., there are multiple growing seasons), the actual evapotranspiration of a year, $ET_{a,y}$, is calculated as the weighted average (with respect to the area A_n cultivated during the growing period n with ($n = 1, 2, ..$) of the total actual evapotranspiration $ET_{a,LPG,n}$ (mm) of each growing season, as:

$$ET_{a,y} = \frac{\sum_n ET_{a,y,n} \cdot A_n}{\sum_n A_n} \tag{2.2.2}$$

In figure 2.2.1 and in figure 2.2.2 are reported the worldwide map available for the primary soybean

uWF referred to the yearly ET_a and the actual yield ($tonnes/ha$) of the reference year 2000.

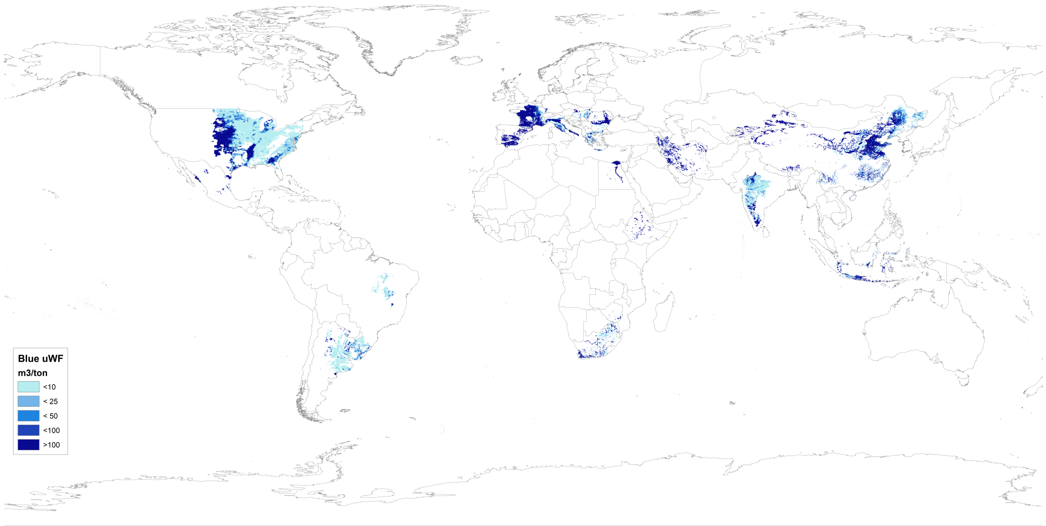

Figure 2.2.1: Blue uWF for soybean (m^3/tonnes) referred to the yearly ET_a and the actual yield $tonnes/ha$ of the reference year 2000 at 5 arc min spatial resolution (Tuninetti et al., 2015),

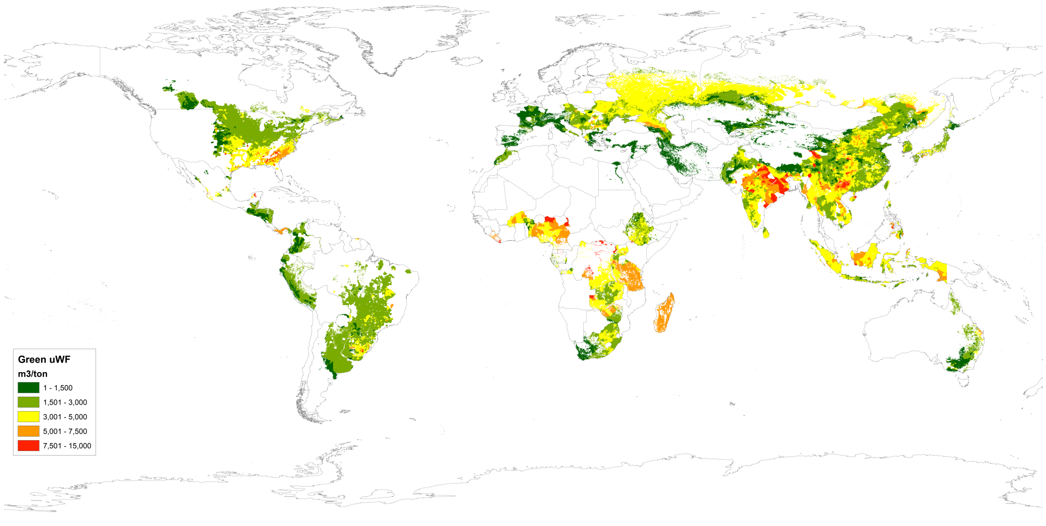

Figure 2.2.2: Green uWF for soybean(m^3/tonnes) referred to the yearly ET_a and the actual yield (tonnes/ha) of the reference year 2000 at 5 arc min spatial resolution (Tuninetti et al., 2015)

2.3 Sub-national agricultural land harvested: area and crop yields

Monfreda et al. provide resolute land use data sets created by combining national, state, and county level census statistics with global data set of croplands on a 5 min by 5 min latitude - longitude grid. The resulting land use data sets depict the reference year 2000 harvested area and yield of 175 distinct crops of the world. The single value referred to year 2000 is the average of all years available between 1997 and 2003. Where no data were available between these years, the average is between 1990 and 1996. For a very small number of cases where the agricultural statistics report missing data values are interpolated. These data sets still represent the most suitable source for detailed production and yield valued for a extended range of crop at the 5 arc min grid level worldwide. This study relies on Monfreda et al. (2008) soybean yields, to build a framework of analysis consistent with the uWF data, set as well to the reference year 2000 and available at 5 arc min grid level.

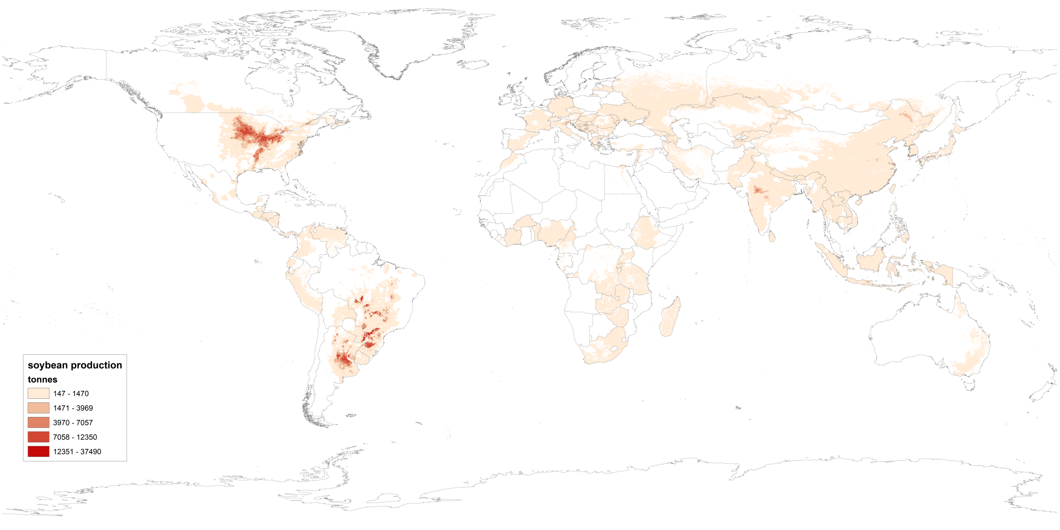

Figure 2.3.1: Soybean production worldwide (tonnes), referred to year 2000 at 5 arc min spatial resolution

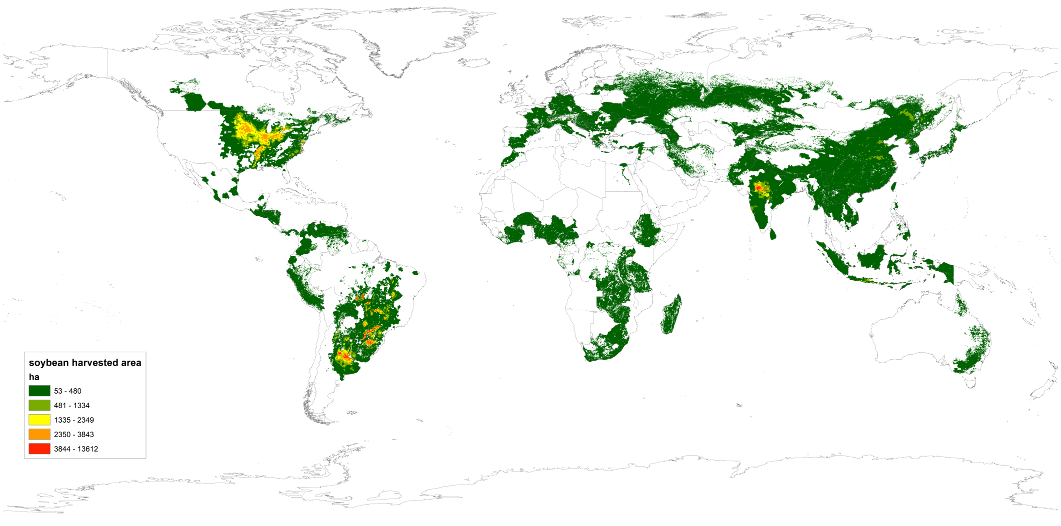

Figure 2.3.2: Soybean harvested area worldwide,(tonnes/ha), referred to year 2000 at 5 arc min spatial resolution

2.4 Sub-national land use: biomes influenced by agriculture

Ellis and Ramankutty mapped the interaction between human activities and natural biomes worldwide quantifying its entity at 5 arc min spatial resolution through the anhtopogenic biomes, as in figure 2.4.2. The anthopogenic biomes, also known as *anthromes*, are obtained on the basis of global data for population (urban, non-urban), land use (percent area of pasture, crops, irrigation, rice, urban land), and land cover (percent area of trees and bare earth). The anthopogenic biomes identified are 21, grouped into six major categories - dense settlements, villages, croplands, rangeland, forested and wildlands, described in figure 2.4.1. The overall ecosystemic process is shaped as:

$$Ecosystem\,processes = f(population\,density, land\,use, biota, climate, terrain, geology) \quad (2.4.1)$$

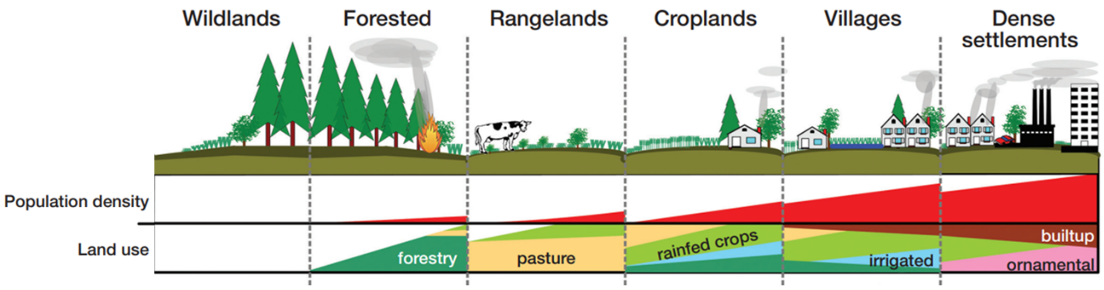

Figure 2.4.1: Conceptual model of anthropogenic biomes structured by population density (logarithmic scale) and land use (percent land area), (Ellis and Ramankutty, 2008).

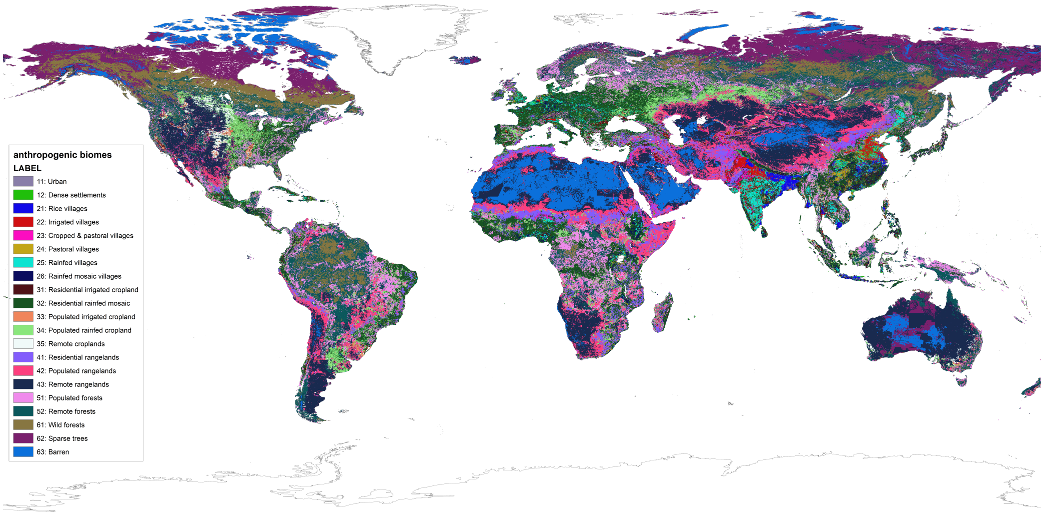

Figure 2.4.2: Anthropogenic biomes worldwide, (Ellis and Ramankutty, 2008)

Ellis and Ramankutty highlights the importance of anthrobiomes in improving the assessment and understand the relation between human activities and the surrounding ecosystems, suggesting that it is not sustainable keeping separate the natural biomes "concept" from its antrhopogenic interactions when addressing to mitigate climate change effects or improving the natural resource sustainable management of the human activities, being humans an embedded part of the ecosystems. They underpin how anthromes can offer more accurate descriptions of ecological patterns within the terrestrial biosphere than conventional biome classification that describes vegetation patterns relying only on climatic and geological variations.

2.5 Sub-national suitability for soybean production: climatic potential yields

Licker et al. provide spatial datasets of both the climatic potential yields and yield gap patterns for 18 crops, maize, wheat, rice, soybean, barley, millet, rye, sorghum, cassava, potato, sugarcane, sugar beet, groundnuts, oil palm, rapeseed or canola, cotton, pulses and sunflower, around the year 2000. These datasets depict the regions of the world that meet their climatic potential, and highlight places where yields might potentially be raised. In this study, of this data-set particular attention is posed to climatic potential yields for soybean, in order to evaluate the current yield gap of the Italian existent soybean plantations. The data-set relies on Monfreda et al. (2008) harvested land and production mapping, thus referencing to a time window from 1997 to 2003 at a 5 arc minute grid level. The world's crop yield depends on different features such as climate, soil quality, genetic potential and human management (including irrigation, fertilization and other planting practices). The work of Licker et al. (2010) remapped these yields in 100 different climatic zones in order to highlight the effect of climate, and to isolate variations in yields attributable to the other yield drivers. The climatic classification relies on the relationship between climate and global biomes suggested by Prentice et.al, 1992. Thus two variables concur to define the climate zones: the growing degree days of the crop and the soil moisture index. The *Growing Degree Days* (GDD) is one of the feature utilized to describe a climate region in terms of plant growing period:

$$GDD = \sum_{i=1}^{365} max(0, T_i - T_b) day - degrees \tag{2.5.1}$$

where T_i is the temperature in °C at each time step and T_b is a crop-specific baseline temperature, for soybean evaluated at 8°C, as in Ramankutty et al. (2002). The crop soil moisture index is instead the ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET). The yields are distribuited over a 10×10 matrix of GDD and average, annual crop soil moisture availability with 100 different climate zone combinations, as in figure 2.5.1 for soybean. The climatic potential yield is the 90% percentile yield achieved for a given crop in a given climatic zone. The climatic potential yields do not represent the absolute "maximum" yields that a crop will ever be able to achieve; rather, they represent the maximum, climatic-potential yields currently being achieved on croplands in any given climate zone in the world in around 2000, with management practices and varieties that have already been adopted by farmers. This "maximum" is achievable given 2000 technology, using the best management practices and high-yielding crop varieties, for each climate zone.

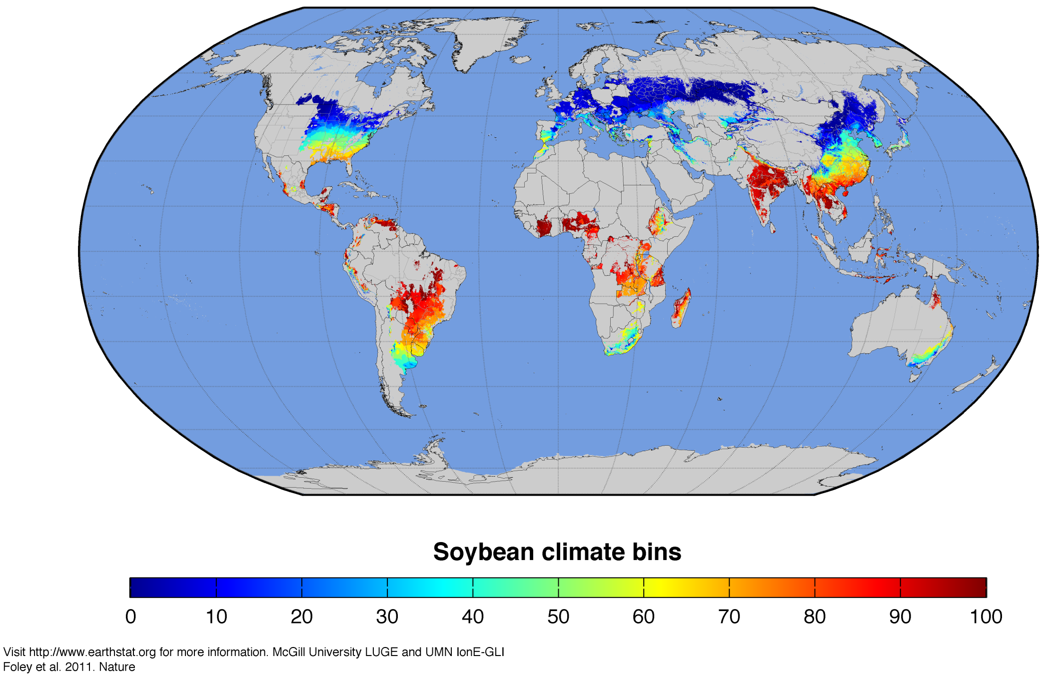

Figure 2.5.1: Soybean climate bins, at 5 arc minute spatial resolution, with a base temperature of 8° C (Licker et al., 2010)

2.6 Country water footprint in time: the CWASI database

The CWASI database, developed within the EU-funded ERC project *Copying with WAter Scarcity In a Globalized world*, offers a set of data on national water footprint and virtual water trade (VWT) for hundreds of agricultural goods. The water footprint is expressed as unit water footprint, uWF ($m^3/tonne$), estimated at the country scale for every year over the period 1961-2016. The uWF of this database also takes into account the annual variability of the uWF of crops, the import and production in the uWF and the tracing of the agricultural goods up to the production through the international trade Tamea et al. (2020). From FAO, the database collected 31 years of trade (1986-2016) and 56 years of production (1961-2016). The number of commodities includes all products in the "Crop" production statistics of FAO: 357. Among all commodities, some are considered in both trade and production data, some appear only in trade and some other appear only in production. The main reason is that production data are only available for primary goods and for few processed goods, while trade includes primary and a larger set of processed goods. The countries covered are all the 255 countries listed as producing or trading between 1961 and 2016. Yields and harvested land also refers to FAOSTAT data at the national scale. The uWF is calculated with the Fast-Truck method proposed by Tuninetti et al. (2017) which enhance the water footprint provided by WaterStat (Mekonnen Hoekstra, 2010) with the temporal variability, which is mainly expressed by a ratio of agricultural yields. Yield implicitly expresses many factors, including environmental and climatic conditions, harvested areas and agricultural practices and its temporal variations dominate over the variability of the evapotranspiration volumes. The uWF of production (uWF_p) of a specific crop p in a generic year t for the country c is calculated as:

$$uWF_{pc,p,t} = \overline{uWF_{pc,p,T}} \cdot \frac{\overline{Y_{c,p,T}}}{Y_{c,p,t}} \tag{2.6.1}$$

where $\overline{uWF_{pc,p,t}}$ is the reference unit water footprint provided by WaterStat corresponding to an average in the period $T = 1996 - 2005$, $\overline{Y_{c,p,t}}$ is the crop yield over the same period, $Y_{c,p,t}$ is the annual crop yield in a generic year t in the range 1961-2016.

The average crop yield $\overline{Y_{c,p,t}}$ is obtained as an average of the annual yields in the years 1996-2005, weighted by the harvested areas across the years in country c.

The actual evapotranspiration of crops, equal to the average in the period is considered thus implicitly constant. This has been shown to introduce an uncertainty around ±10% of the uWF estimates for wheat, maize, rice, soybeans, which is lower than the model uncertainty in the water footprint assessment (Tuninetti et al., 2017). The uwF values for Brazilian soybean, along with the 255×255 production matrix of the CWASI database, are in this study utilized as the validation tools of the traced production resulting from the Trase database elaboration, both to confirm the conformity of the volumes at study and of the soy equivalent conversion trough the weight factors of Mekonnen and Hoekstra (2010).

2.7 Country supply-chain allocation: FAOSTAT data

The Food and Agricultural Organization of United Nations provides numerous statistics at the national scale worldwide for crop production, crop processing, animal and livestock data, trade data and other environmental and social data related to agriculture. In this study the variables of interest have been the national productions data for primary and processed soybean of Brazil and Italy, the detailed trade matrix of import and export and the Italian new Food Balance Sheet, all data referred to year 2018. The Food Balance Sheet (FBS) is the most comprehensive collection of data available on a very large set of countries that is related to food commodities supply and food commodity utilization Jacobs and Sumner (2002). Thus, this set has been used to unfold the Italian utilization of imported soybean in 2018. Updated data were available from the 21st of January 2021, relying on a new imputation methodology of missing data. The key difference between the new and old food balances methodologies is the absence of a balancer variable. In the past, one of the components of the FBS (often stocks, industrial utilization or feed) would take on the outstanding unbalanced amounts thus inheriting all the statistical errors. With the new Imputation methodology (Browning and Kao) the estimation of the FBS components not provided by countries are generated by dedicated modules; and a balancing mechanism will then proportionally spread the imbalances out among all the components FAOSTAT (2020). This new imputation method works on Ensamble Learning, which relies on a weighted average between different modeling expressions. The weight of each model is assigned according to its fitting to the national trend in study. This method helps to better predict the missing data, avoiding to choose a only model which may get far from the real values of the data set, even if it may be very representative in other parts of it (Browning and Kao). FBS gives the total quantity of foodstuffs produced in a country added to the total quantity imported and adjusted to any change in stocks that may have occurred since the beginning of the reference period gives the supply available during the reference period. On the utilization side a distinction is made between the quantities exported, fed to livestock, used for seed, put to manufacture for food use and non-food uses, losses during storage and transportation, and food supplies available for human consumption.FBS shows for each food item - i.e. each primary commodity and a number of processed commodities potentially available for human consumption - the sources of supply and its utilization FAOSTAT. The Supply Utilization Accounts of soybean FBS, refers to soya beans, soya sauce, soya paste, soya curd in primary equivalent tonnes, being the edible products for human diet. Soybean oil and soybean cake are not included in this path as a source input, but they figure at the bottom of the utilization supply as the products of the processing block. Indeed, FBS main scope is that of underpin the nutritional contribution of a product in the national supply at study, referring to the items concurring to yearly kcal per capita intake. Data about soybean oil and cake import and production of Italy in the study relies though on the FAOSTAT (a) sheets of import and production of processed commodities. Regarding the import quantities for 2018, from the detailed trade matrix (FAOSTAT, c), while the soybean oil import from Brazil figures null, the import of soybean cake is estimated to be equal to 205'567 tonnes. Hereafter they are itemized strategical definitions of supply-chain patterns in FBS, from FAOSTAT and FAO (2001)

- Processing refers to quantities of a commodity that enter a manufacturing process for the production of a derived food product. Food processing quantities are linked to the production of derived commodities through extraction rates;
- Stock: comprises changes in stocks occurring during the reference period at all levels from production to the retail stage, i.e. it comprises changes in government stocks, in stocks with manufacturers, importers, exporters, other wholesale and retail merchants, transport and storage enterprises, and in stocks on farms. In practice, though, the information available often relates only to stocks held by governments;
- Feed: comprises amounts of the commodity in question and of edible commodities derived therefrom not shown separately in the food balance sheet (e.g. dried cassava, but excluding

by-products, such as bran and oilcakes) that are fed to livestock during the reference period, whether domestically produced or imported.

- Seed: comprises all amounts of the commodity in question used during the reference period for reproductive purposes.
- Losses: those quantities of commodity that leave the production/supply chain at any stage from post-harvest up to the retail level.

2.8 Administrative data of Brazil

Brazilian Municipalities, States and National borders Shape file of Brazilian Municipalities censed by the *Istituto Brazileiro de Geografia e Estatistica*, IBGE, and sourced from The Humanitarian Data Exchange, HDX, of United Nations Office of Humanitarians Affairs, (OCHA). The administrative census of Brazil is referred to the year 2020 and counts 5572 municipalities, distributed over 27 federal states and identified by a unique georeferencing code. The attribute arrays of municipalities and states have been validated and put in unique correspondence through the georeferencing code with Trase data arrays reporting municipalities and states. From de Geografia e Estatística IBGE it has been sourced also the distribution of biomes over the territory and integrated with the same information recorded by Trase. The Brazilian hydrology, the world map and other administrative or geological features have been sourced from open source GIS databases. From IBGE agricultural data at the state scale are utilized as supporting material for the study. The latest agricultural census of Brazil refers to the year 2017; a dedicated panel for soybean farmers has been accessed to deepen the understanding of production patterns throughout the Brazilian federal states.

2.9 Italian agricultural census and administrative data

Data by ISTAT are collected following an estimation methodology. The estimates are made on the basis of assessments by local experts located throughout the territory. These estimates may include the results of direct land-based checks, as well as indications from external sources (e.g. professional bodies and producer associations, administrative sources, auxiliary data sources related to the estimated cultivation). The crops under investigation are different for each month and take into account the phenological stage of cultivation. For this reason more than one estimate can be determined for each crop during the agricultural year. In the case of soybean, data have been sourced for the yearly harvested production - expressed in quintals and then converted in (*tonnes*)- and cultivated lands (*ha*) of the Italian provinces. Dataset availability for soybean starts from year 2006 until 2020. Between the possibility to select among the yearly total production or the yearly harvested production, the second is chosen to calculate the yearly yields at the province scale. All data at the province scale are surveyed, except for the provinces in the region of Marche, which are estimated. Thus, when calculating the yields, the provinces of Marche stand out as possibly over-estimated with respect to the national yield average reported by FAOSTAT (a) in 2018, equal to 3.63 $tonnes/ha$. The survey schedule is set out in the Istat-Ministry of Agricultural, Food and Forestry Policies-Regions Memorandum of Understanding. In accordance with European Regulation No 543/2009 on statistics on crop products, the National Statistical Office carries out the survey on the sowing intentions of certain herbaceous crops of a cyclical type, using CAWI - (Computer assisted web interviewing- and CATI- (Computer Assisted Telephone Interviewing) mixed techniques, from November until January. The purpose of the survey is to determine, on the basis of the sowing intentions of farmers, an early estimate of changes in the areas invested in the various crops at the beginning of the agricultural year. It is a sample survey of some 15000 holdings, the sample is random, it has been selected from the list of agricultural units prepared by ISTAT through the integration of administrative and statistical sources, and its size is determined in such a way as to ensure accurate estimates at regional level (ISTAT).

2.10 ESA surveying land use change: the Copernicus Program

Copernics program is part of the ESA's Earth Observation Strategy 2040 which covers the period from 2015 to 2040. The previous program of ESA's Earth observation, from 1998 to 2012, was called the Global Monitoring for Environment and Security (GMES) program. Since 2014, along with the dismissal of Envisat, a new family of satellites, called Sentinels, gave continuity and enhanced the observation program. Copernicus relies on a mixed set of sources, including satellites and in situ sensors (e.g., ground stations, airborne/seaborne instruments) and provides users with services through a free data policy and open source cloud, offering insights and informative contents. The observed categories are six: land management, marine environment, atmosphere, emergency response, security, and climate change. Each Sentinel of the satellite family is dedicated to one of the cited category (Aschbacher, 2017) (Showstack, 2014). In this study, the land surveying observations from Sentinel-2A and Sentinel-2B, launched respectively in June 2015 and in March 2017, along with the radar observations from Sentinel-1A, launched in April 2014 and Sentinel-1B, which followed in April 2016, support the spatial analysis of the traced productions and allow to identify some macro characteristics of the agricultural productions at study, including related land use change over time, cultivation extension and irrigation systems installation. Copernicus is a partnership among European Union and European Space Agency: the European Commission, acting on behalf of the European Union, is responsible for the overall initiative, setting requirements and managing the services. Free data have been sourced from the "Earth from Space" series offered by the European Space Agency online platform.

2.11 Data limitations

The data limitations of the data-sets this work relies on can be grouped in two categories:

- spatial and temporal variability;
- statistical data on agricultural production and supply-chain records.

They belong to the first category the high resolute spatial databases available worldwide at 5 arc minute grid cell, but stuck on the reference year 2000. Still, Monfreda et al. (2008) represents the the best source for a wide brand of agricultural, ecological and environmental data-set at 5 arc min spatial resolution and fundamental studies are average based on year 2000. Thus, raster data sets, as the uWF by Tuninetti et al. (2015), the climatic potential yield by Licker et al. (2010), the anthromes by Ellis and Ramankutty (2008) evidence a time defect, especially because of the rapid growing faced by the agricultural expansion in the latest 20 years and the increase of productivity. Specifically, in the merging between the sub-national production values by Trase, they result missed 23 municipalities, accounting for 6'936 *tonnes* of production. Instead, the climatic potential yield, being the expected "maximum" yield achievable in 2000 within climatic possibilities and agricultural management practises, it is expected to be under-estimated in the current scenario. The second set of limitations engages the issue of supply chain detection and of statistical record of agricultural commodities production and utilization. Trase database, which remarkably improves the supply chain tracing framework, unfolding the trade flows providing sub-national data never available as far, still deals with unknown sourcing municipalities at the production scale. Though, the upgrading versions of the SEI-PCS model are enhancing the filling of this gap and the current version 3.2 for Brazilian soybean suggests that those unknown export flows may come from the State of Sao Paulo, being this an important retailing and processing spot, but for this reason may not be the production location. The unknown trade flows in the case of Italy counts 23 municipalities, equivalent to 76'300 *tonnes*, generating a loss in the supply-chain detection equal to the 20% of the total recorded production. At the bottom of the supply-chain of this study the limitations are instead set by the FAOSTAT production sheets. Indeed, concerning the soybean secondary items production, data for soybean cake are available for Italy just until 2013, thus, the processing quantity of soybean cake in 2018 in the Italian supply is calculated in this work as the difference between the total processing amount within the Italian utilization supply (available from FBS) and the soybean oil production quantity available for 2018.

Chapter 3

Methodology

This study has the aim of proposing a methodology to assess the Virtual Water flows at the sub-national scale by connecting the local environmental impacts, happening at the scale of the production sites, to the final consumer and the associated supply and utilization chains. In particular, the goal is to trace the water footprint volumes of soybean production associated to the import of commodities and build the bipartite network between the local production - and the related trader companies- and the importer country. Also, the sub-national scale of analysis, enables to add to the water footprint assessment other environmental indicators, such as the land use change, the anthropogenic interactions with ecosystems, the climatic variability and the water resources exploitation. The method employs and merges different environmental databases with trade data, as shown in chapter 2, which all together contribute to assess the water footprint flows from different perspectives and underpin the mutual results. A flow diagram representing the main steps on which the method relies on is illustrated in figure 3.0.1 and below described.

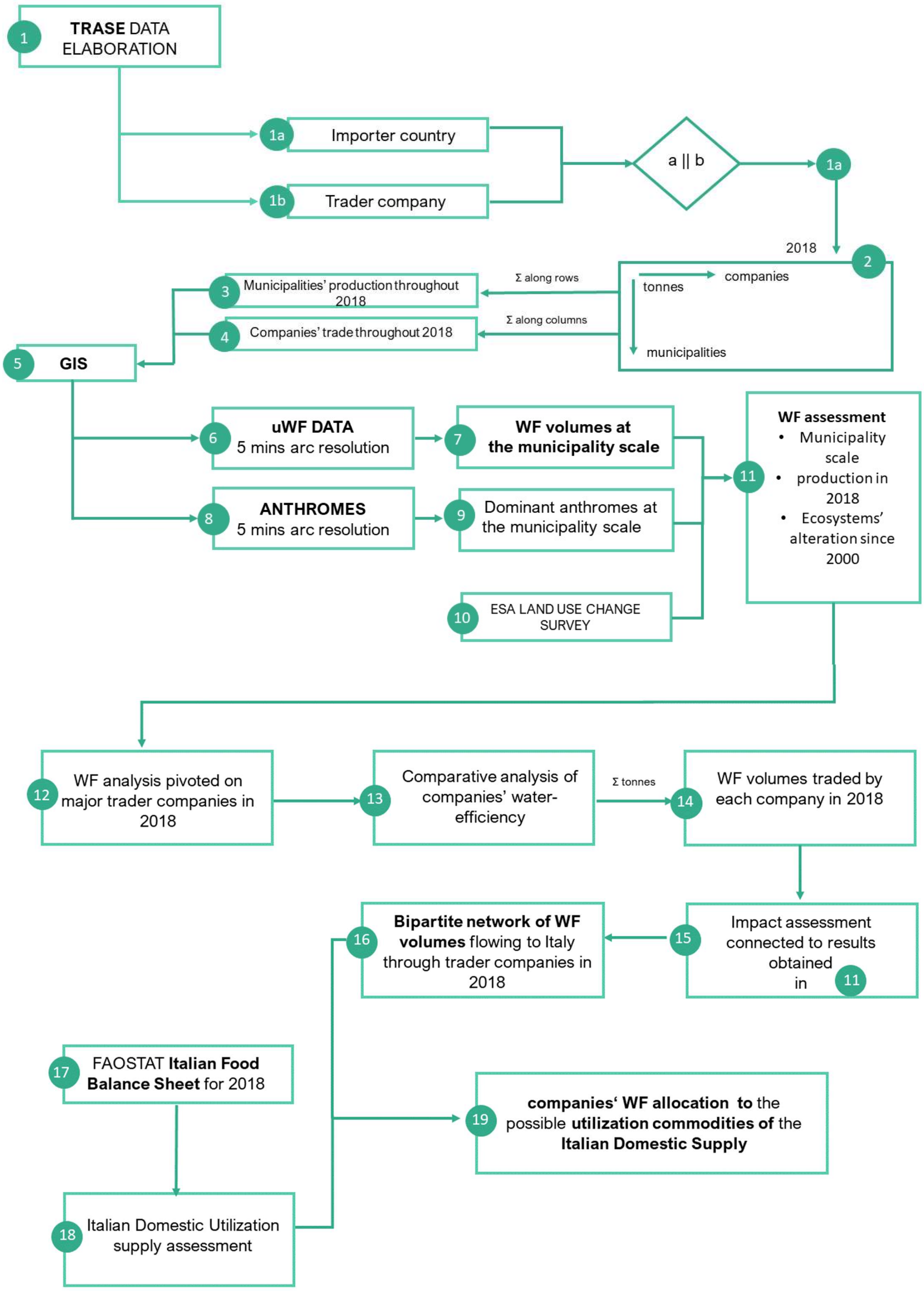

Figure 3.0.1: Flow Diagram reporting the main logical steps of the method developed in the present thesis

The first step has been to elaborate the trade data from Trase with an algorithm which allows to choose between two options of studying: focusing on the importer country, or on a specific trader company; in this work the first option is the one selected. The elaboration of trade data producing a matrix, whose columns show the trader companies engaged and the rows show the municipalities involved in the production of the analyzed commodity for the chosen year, for the importer country selected at step (1). Summing along rows or columns brings to two results, pivoted on the possible variable "municipality" or "company". These results are fitted for the spatial analysis in a Geographic Information System, where they are joined with the administrative shapefile of Brazil, obtaining the spatial distributions of the sourcing municipalities (e.g., those located in Brazil) of the importer country (e.g., Italy) and their relative production over the studied year. The first step in GIS is to represent the production of each municipality, carried on in the entire 2018 throughout the Brazilian country. The following step is to elaborate the uWF data: through raster calculations, cell values are averaged on the municipalities detected, obtaining the uWF at the municipality scale (6) to be multiplied by the trade data elaborated in step (3) or (4). Step (7) is the product between step (3) and (6). Similar raster operations have been made for the anthromes data in step (8), but in this case, through histogram of frequency, the most frequent cell value occurring in a municipality and in a federal state is highlighted to detect the dominant anthromes in the selected area. Step (10) brings the contribution of the ESA land use change survey, the Copernicus Program, in expanding the results from steps (5), (7) and (8). Step (11) assess the findings of the previous steps and evaluates the impacts of production at the municipality scale. The information resulted from step (4) and elaborated in (5) are illustrated in the step (12), water-efficiency in terms of uWF is analyzed for each company in (13). The step (14) is the product of (4) and (6), assessed in (15) with the support of the findings in (11). Step (16) builds the bipartite graph between municipalities and associated companies to the importer country. It takes into account the leading trade companies of the examined export. Through (17) and (18) it is reconstructed the allocation of the imported soybean in the importer supply to assign the WF volumes of top-trading companies of step (16) to an expected commodity of utilization in the domestic supply of the importer country. In this chapter, all the funding blocks will be discussed in detail.

3.1 Elaboration and database organization

In order to shape the Trase data in the way that they can best serve this study, an algorithm has been developed to easily access the spatial information of all the municipalities involved in the production for the export to a selected importer country. The shaping has been designed thinking about the spatial representation of the water footprint and of the virtual water flows: the focus has been posed on the municipality of production and on the country of destination. The information of interest in Trase database are the flows between the two nodes, namely the municipality and importer Country. The algorithm is built to allow a multi-scale analysis: for each municipality the cumulative production is obtained of an exporter group per year, so that if one is interested in the analysis of a production connected to a specific exporter company, it's possible to read this information directly. Alternatively, the cumulative production is obtained of a specific municipality for the whole year at study. The shaping algorithm has been written in MATLAB R2019b and the GIS system employed is ArcMap 10.7.1 of ArcGis by ESRI.

Trase database in bulk format, presents the following options for download:

Table 3.1.1: Bulk data selected options for Trase database download

Commodity	soybean
Exporter group	all companies
Year	2018
Country of production:	Brazil
Importer Country	all
Importer group	all companies

The input data have the structure reported in figure 3.1.1

BIOME	STATE	MUNICIPALITY	EXPORTER GROUP	COUNTRY	SOY_EQUIVALENT_TONNES	TRASE_GEOCODE
AMAZONIA	RONDONIA	ABADIA DE GOIAS	DOMESTIC CONSUMPTION	BRAZIL	1.00E-09	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	CHINA (MAINLAND)	6.27E+01	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	CHINA (MAINLAND)	8.78E+01	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	CHINA (MAINLAND)	2.71E+02	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	JAPAN	2.58E+01	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	PORTUGAL	1.88E+00	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	THAILAND	3.70E+00	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	TURKEY	3.14E-01	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	THAILAND	1.07E+00	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	SPAIN	6.18E+00	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	CAYMAN ISLANDS	6.21E+00	BR-5200050
AMAZONIA	RONDONIA	ABADIA DE GOIAS	MITSUBISHI CORPORATION DO BRASIL	CHINA (MAINLAND)	1.54E+02	BR-5200050
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	9.09E+02	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	IRAN	1.11E+01	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	1.03E+02	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	SOUTH KOREA	1.74E+00	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	2.07E+01	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	1.31E+03	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	TURKEY	9.36E+02	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	6.02E+02	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	BANGLADESH	2.50E+00	BR-3100104
AMAZONIA	RONDONIA	ABADIA DOS DOURADOS	GAVILON	CHINA (MAINLAND)	1.47E+03	BR-3100104

Figure 3.1.1: Input data

Being the objective of the study highlighting the WF volumes flowing from a specified municipality to an importer country via a specific trader company, the analysis is lead through spatial analysis, thus, the output has been thought to create new layer features suitable for a Geographic Information System is shown in figure 3.1.2:

	Exporter Group 1	Exporter Group 2	…	Exporter Group m
Municipality 1	Soy equivalent tonnes			
Municipality 2				
…				
Municipality n				

Figure 3.1.2: Output design

This output will turn then into an attribute table, to be join trough the tool "Join" in ArcMap, with the shapefile of Brazilian Municipalities. This shapefile has been imported in Matlab as a string array in order to create the keystone for the join.

3.1.1 Algorithm structure

In Figure 3.1.3 the flow diagram of the algorithm is represented. A description of the main logical steps follows the scheme.

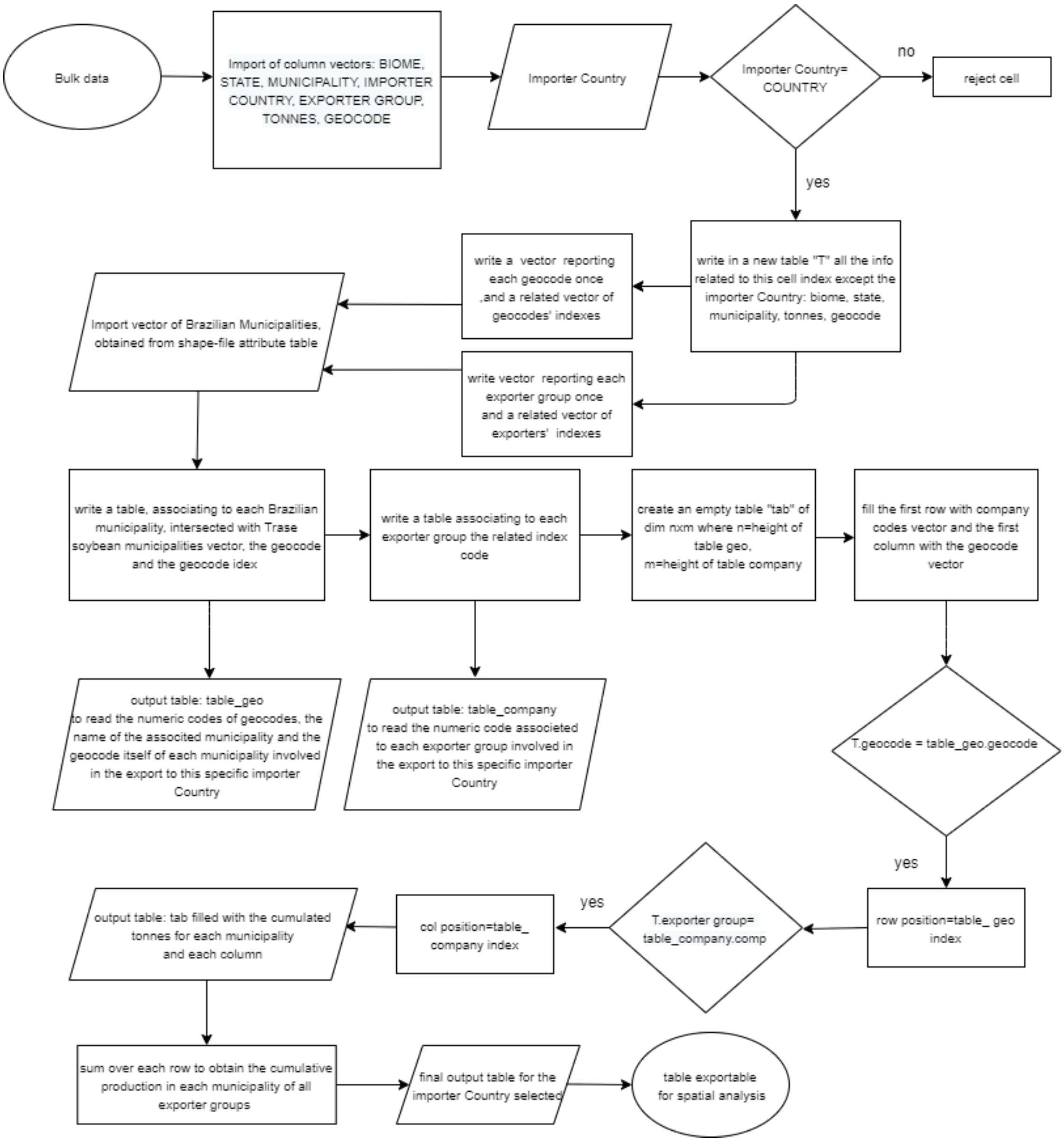

Figure 3.1.3: Flow chart representing the algorithm for data elaboration and extraction

The first step is introducing as input in the command window the importer country, e.g Germany, of interest. The algorithm selects the cells that contain Germany in the column “importer country”. It is obtained a table listing for each Brazilian municipality the tonnes of soybean imported by Germany. In this operation, the "unknown" municipalities have been detected and erased from the list, not have zeros in the final output. Despite this, the sum of soy equivalent tonnes from untraced municipalities is recorded in the input data and is quantified. From now on, all information are filtered for the importer country: the municipalities and the exporter groups will be just the ones involved in the production and trade market for the selected country.

To proceed, this first result must be reordered to obtain a unique correspondence between the municipality, the exporting company and the exported tonnes. In trade documents it can occur to have more than one record for the same municipality and same exporter company, as reported in figure 3.1.4).

BIOME	STATE	MUNICIPALITY	EXPORTER GROUP	SOY EQ TONNES	GEOCODE
'MATA ATLANTICA'	'PARANA'	'ABATIA'	'LOUIS DREYFUS'	1.69E+02	'BR-4100103'
'MATA ATLANTICA'	'PARANA'	'ABATIA'	'LOUIS DREYFUS'	2.20E+02	'BR-4100103'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'BUNGE'	3.64E-01	'BR-4200408'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'BUNGE'	1.60E+03	'BR-4200408'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'CERVEJARIA PETROPOLIS'	3.18E+03	'BR-4200408'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'CERVEJARIA PETROPOLIS'	1.02E+03	'BR-4200408'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'BUNGE'	9.81E+01	'BR-4200408'
'MATA ATLANTICA'	'SANTA CATARINA'	'AGUA DOCE'	'BUNGE'	9.69E+02	'BR-4200408'
'CERRADO'	'SAO PAULO'	'AGUAS DE SANTA BARBARA'	'LOUIS DREYFUS'	1.51E+02	'BR-3500550'
'CERRADO'	'SAO PAULO'	'AGUAS DE SANTA BARBARA'	'LOUIS DREYFUS'	1.96E+02	'BR-3500550'
'MATA ATLANTICA'	'RIO GRANDE DO SUL'	'AGUDO'	'BIANCHINI'	2.91E+02	'BR-4300109'
'MATA ATLANTICA'	'RIO GRANDE DO SUL'	'AGUDO'	'BIANCHINI'	7.84E+01	'BR-4300109'
'MATA ATLANTICA'	'SAO PAULO'	'ALAMBARI'	'LOUIS DREYFUS'	9.41E+00	'BR-3500758'
'MATA ATLANTICA'	'SAO PAULO'	'ALAMBARI'	'LOUIS DREYFUS'	1.22E+01	'BR-3500758'
'MATA ATLANTICA'	'PARANA'	'ALMIRANTE TAMANDARE'	'LOUIS DREYFUS'	2.15E+00	'BR-4100400'
'MATA ATLANTICA'	'PARANA'	'ALMIRANTE TAMANDARE'	'LOUIS DREYFUS'	2.79E+00	'BR-4100400'
'MATA ATLANTICA'	'RIO GRANDE DO SUL'	'ALTO ALEGRE'	'BIANCHINI'	2.29E+03	'BR-4300554'
'MATA ATLANTICA'	'RIO GRANDE DO SUL'	'ALTO ALEGRE'	'BIANCHINI'	6.19E+02	'BR-4300554'
'CERRADO'	'MATO GROSSO'	'ALTO ARAGUAIA'	'BUNGE'	3.49E-01	'BR-5100300'
'CERRADO'	'MATO GROSSO'	'ALTO ARAGUAIA'	'BUNGE'	1.54E+03	'BR-5100300'
'CERRADO'	'MATO GROSSO'	'ALTO ARAGUAIA'	'LOUIS DREYFUS'	2.59E+00	'BR-5100300'
'CERRADO'	'MATO GROSSO'	'ALTO ARAGUAIA'	'BUNGE'	9.41E+01	'BR-5100300'

Figure 3.1.4: Problem of not unique correspondence between municipality and exporter company, example for France

Consequently, in the process, the tonnes belonging to the same municipality and to the same exporting company are aggregated into a only row corresponding to the unique match "municipality-trader company".

Results are reported in the following two tables:

- a table reporting the exporter groups names and their relatives identification codes;
- a table reporting the geocode of the municipality, the name of the municipality and the relatives identification codes.

The shortcut of the table obtained for municipalities is reported in figure 3.1.5. The real dimension of the entire table is 151x3 - 151 Brazilian municipalities involved in soybean production for German import per 3 attributes (name, geocode, identification code). The companies' table shortcut is represented in figure 3.1.6.

MUNICIPALITY	GEOCODE	CODE_g
ABELARDO LUZ	BR4200101	12
ABREULÂNDIA	BR1700251	15
ÁGUA DOCE	BR4200408	54
ALTAMIRA DO PARANÁ	BR4100459	136
ALTO ARAGUAIA	BR5100300	147
ALTO GARÇAS	BR5100409	153
ALTO PIQUIRI	BR4100707	163
ALTO TAQUARI	BR5100607	167
ARAGUACEMA	BR1701903	312
ARAGUARI	BR3103504	320
ASSIS CHATEAUBRIAND	BR4102000	412
BALIZA	BR5203104	464
BALSAS	BR2101400	474
BARREIRAS	BR2903201	541
BITURUNA	BR4102901	630
BOA VENTURA DE SÃO ROQUE	BR4103040	640
BOM JARDIM DE GOIÁS	BR5203401	672
BOM JESUS DE GOIÁS	BR5203500	683
BRASNORTE	BR5101902	757
CAFELÂNDIA	BR4103453	876
CAMPINA DO SIMÃO	BR4103958	945
CAMPO ERÊ	BR4203501	968
CAMPO GRANDE	BR5002704	973
CAMPO MOURÃO	BR4104303	981
CAMPO NOVO DO PARECIS	BR5102637	984
CAMPOS DE JÚLIO	BR5102686	990
CAMPOS LINDOS	BR1703842	994
CANARANA	BR5102702	1009
CANTAGALO	BR4104451	1042
CAPANEMA	BR4104501	1049
CAPINÓPOLIS	BR3112604	1068
CASEARA	BR1703909	1163
CATALÃO	BR5205109	1181
CHOPINZINHO	BR4105409	1264
CONFRESA	BR5103353	1358
CORBÉLIA	BR4106308	1380

Figure 3.1.5: Municipalities and geocodes Table, example for Germany

EXPORTER GROUP	CODE
AB COMERCIO DE INSUMOS	1
ABENGOA BIOENERGIA AGROINDUSTRIA	2
ACO MINERACAO LIMITADA	3
ADAMA BRASIL	4
ADAMI SA MADEIRAS	5
ADDN ASSISTENCIA TECNICA COMERCIO E INDUSTRIA LTDA	6
ADECO AGROPECUARIA BRASIL	7
ADECOAGRO	8
ADELBRAS INDUSTRIA E COMERCIO DE ADESIVOS	9
ADM	10
ADRIANA AGRICOLA	11
AESA AUTOMOLAS EQUIPAMENTOS LTDA.	12
AFG BRASIL	13
AGRICOLA ALVORADA	14
AGRINVEST BRASIL	15
AGRITER AGRONEGOCIOS	16
AGRO LATINA	17
AGROBOM COMERCIO E INDUSTRIA DE CEREAIS LTDA - EPP	18
AGROCONTATO COMERCIO E REPRESENTACOES DE PRODUTOS AGROPECUARIOS LTDA	19
AGRODANIELI	20
AGROEXPORT TRADING E AGRONEGOCIOS	21
AGROINDUSTRIAL CAMPO REAL LTDA	22
AGROLOGICA AGROMERCANTIL	23
AGROMON AGRICULTURA E PECUARIA	24
AGRONOVA COMERCIO DE INSUMOS AGRICOLAS EIRELI	25
AGROPECUARIA 3 PODERES - COMERCIO, EXPORTACAO E IMPORTACAO LTDA	26
AGROPECUARIA CATARATAS	27
AGROPECUARIA GLOBAL LTDA - ME	28
AGROPECUARIA LABRUNIER	29
AGROPECUARIA SANTA MARIA DO CERNE	30
AGROVENCI - COMERCIO, IMPORTACAO, EXPORTACAO E AGROPECUARIA	31
AGROVERDE AGRONEGOCIOS E LOGISTICA	32
ALCOFLAME INDUSTRIA E COMERCIO DE PRODUTOS QUIMICOS E MAQUIN	33
ALIBEM ALIMENTOS	34
ALPHA COMMODITIES S.A.	35
AMAGGI	36
AMAGGI & LD COMMODITIES	37
ARAUJO & SARAIVA LTDA	38
ASA INDUSTRIA E COMERCIO	39
AUGUSTINHO COMERCIO EXPORTACAO E IMPORTACAO LTDA	40
AURELIO GOETTEMS EM RECUPERACAO JUDICIAL	41
BALDO	42
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BIANCHINI	44
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Figure 3.1.6: Shortcut of the Exporter group Table repoting Company and Identification Code

By comparison of the georeference codes and the exporter codes, it is obtained the final output table designed as in figure 3.1.2, in which along the first column there are the municipalities (identified by their geographical code) and in the first row the exporter companies which handle the export for the analyzed importer Country. The output is readable referring to tables of municipalities and companies codes, of which a shortcut id represented in figure 3.1.5 and in figure 3.1.6. The result for Germany is a table of dimensions 151x15, reporting 151 municipalities involved in soybean production for German import and 15 companies handle the trade among the total 297 operating in Brazilian export. Hereafter in figure 3.1.7 a shortcut of the output obtained for Germany is reported as example - the table has been cut through its first dimension (municipalities list) for simplicity of representation- of dimensions 29 rows per 15 columns instead of 151 rows per 15 columns:

	10	36	54	64	72	74	75	79	151	165	237	248	261	296	TOT
1225	0	0	0	0	0	13143.77	0	0	0	0	0	0	0	0	13143.77
1429	0	0	0	0	0	10999.09	0	0	0	0	0	0	0	0	10999.09
3979	0	0	0	0	0	1242.796	0	0	0	0	0	0	0	0	1242.796
4202	0	0	0	0	0	4000.312	0	0	0	0	0	0	0	0	4000.312
5520	0	0	0	0	0	9919.056	0	0	0	0	0	0	0	0	9919.056
158	0	0	0	0	0	276.892	0	0	0	0	0	0	0	0	276.892
1499	0	0	0	0	0	0	0	0	0	136.4404	0	0	0	0	136.4404
1595	734.4905	0	0	0	0	0	0	0	0	0	0	0	0	0	734.4905
2240	8.305689	0	0	0	0	0	0	0	0	0	0	0	0	0	8.305689
3117	0	0	0	0	0	3102.634	0	0	2054.92	0	0	0	0	0	5157.554
3571	780.5834	0	0	0	0	15075.3	0	0	0	0	0	0	0	0	15855.89
4436	0	0	0	0	0	0	0	0	0	1378.969	0	0	0	0	1378.969
4506	0	0	0	0	0	0	0	0	0	2895.835	0	0	0	0	2895.835
4526	0	0	0	0	0	7665.924	0	0	0	0	0	0	0	0	7665.924
5369	476.6204	0	0	0	0	0	0	0	0	0	0	0	0	0	476.6204
15	0	0	0	0	0	0	0	0	0	249.8089	0	0	0	0	249.8089
312	0	0	0	0	0	0	0	0	0	437.3343	0	0	0	0	437.3343
994	464.4733	0	0	0	0	0	0	0	0	0	0	0	0	0	464.4733
1163	0	0	0	0	0	0	0	0	0	1420.64	0	0	0	0	1420.64
1577	0	0	0	0	0	0	0	0	0	301.3593	0	0	0	0	301.3593
5116	913.9753	0	0	0	0	0	0	0	0	0	0	0	0	0	913.9753
3092	1690.737	0	0	0	0	0	0	0	0	0	0	0	0	0	1690.737
4218	1928.807	0	0	0	0	0	0	0	0	0	0	0	0	0	1928.807
474	140.8583	0	0	0	0	0	0	0	0	0	0	0	0	0	140.8583
4338	59.14066	0	0	0	0	0	0	0	0	0	0	0	0	0	59.14066
1420	9	0	0	0	0	0	0	0	0	0	0	0	0	0	9
320	0	0	0	0	0	0	0	0	0	0	0	0	2810.97	0	2810.97
1068	738.3752	0	0	0	0	0	0	0	0	0	0	0	0	0	738.3752
3137	467.599	0	0	0	0	0	0	0	0	0	0	0	0	0	467.599

Figure 3.1.7: Shortcut of the output table for Germany

To let the shapefile of Brazilian Municipalities and Trase database speak to each other some expedients have been necessary. At first, the algorithm had been thought relying on the comparison between the string array of municipalities' names from the shapefile and the Trase municipalities' array. After the first run, some zeros on the final output table highlighted a mismatch between the two arrays that made the comparison reliability uncertain. The mismatch was due to the fact that more than one municipality in Brazil has the same name, even if it is located in different states. But, both the IBGE shape file and Trase data provide the geocode, the georeferenced code that is unique, differently from the name, for each municipality.Consequently, the algorithm had been modified, relying the logical structure on geocodes arrays. Every comparison has been led by reading the vectors of geocodes. An output table for recording geocode, numeric code of the geocode and municipality name was written in order to read the final output table. At this point, the final matrix was filled in its first column with the codes related to geocodes, instead of the codes related to municipalities' names designed in the first attempt. Further, by observing the shapefile while comparing it to Trase municipalities array, it occurred also that some municipalities of Trase database were not present in the shapefile: the shapefile firstly downloaded was not updated to latest census: it was referred to the census of 2010 and some administrative changes were missed. The census updated to 2020 sourced from was than downloaded and used for building the ultimate version of the algorithm. These debugs, allowed to check to not lose the geographical conformity between Trase data and the IBGE shape file during the reshaping and to check the correct transcription of records while writing the new output.

3.1.2 Output for GIS analysis

This algorithm can be provided for every importer country of interest, in order to analyze his virtual water trade for a commodity analyzed by Trase. Specifically, the code has been run for Italy and other six main soybean European importer from Brazil: Spain, Netherlands, France, Germany, United Kingdom, Denmark and Norway. Along with Italy, all of them except Spain, are partners of the Amsterdam Declarations which in 2015 came after the Declarations on Forest signed during the UN Climate Summit of 2014 held in New York, with the objective of achieve free deforestation supply chains for Palm Oil, Cocoa and Soybean, with set deadline to 2020. Despite the success of the European Alliance for sustainable Palm Oil, initiatives for cocoa and soybean are conversely less effective and definitely less choral, especially for soybean Trase (2018a). The maps of the sourcing production for all the other European countries analyzed are reported in the Appendix Appendix H. In the case of Italy it is obtained an output matrix M of dimension 374×38, 374 traced municipalities per 38 companies, which constitutes the raster data sets represented in the results of chapter 4. The general output for an importer country c for a specific year y can be defined as a matrix M of dimensions $m \times e$ where m is the number of municipalities involved, e is the number of trader companies revealed:

$$[M]_{m\times ec,y} = [municipalities]_{mc,y} \times [exportercompanies]_{ec,y} \tag{3.1.1}$$

In the obtained matrix $M_{italy,2018}$ the cumulative production along columns are found for some minor companies -19 in the case of Italy- equal to zero, this is due to the fact that the vector of municipalities has been filtered of the "unknown", see section section 2.11, so there is a mismatch between known companies and un-traced municipalities, as explained in chapter 2.

In Figure 3.1.8 are reported the logical steps computed to obtain from Trase database also the information about biomes involved and relating them with municipalities and companies in the shaped configuration. These information have been detected separately from the matrix correlating municipalities and trading companies in order to simplify the structures and to facilitate the shaping as designed and illustrated in 3.1.2. Figure 3.1.9 is the map resulted from the processing of the output obtained: it represents the biomes involved in soybean production in 2018 for the entire Brazil.

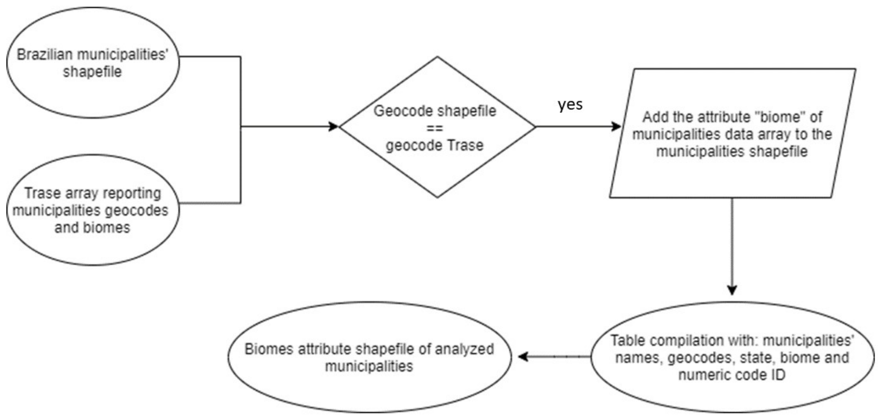

Figure 3.1.8: Shaping data on biomes

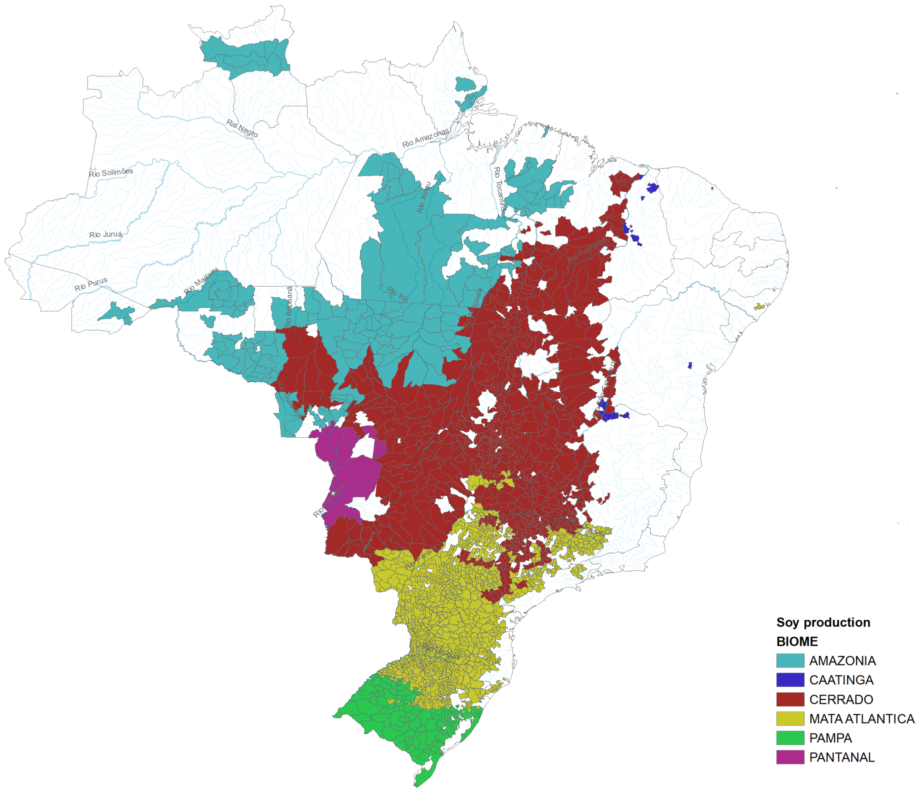

Figure 3.1.9: Brazilian biomes involved in soybean production in 2018

3.2 Data validation

3.2.1 TRASE database for 2016

Table 3.2.1: Tonnes of equivalent soybean exported from Brazil to Italy (Trase, 2016)

Brazilian export to Italy (tonnes)	not localized (tonnes)
$6.57E + 05$	$3.00E + 04$

The difference between the total tonnes exported and the tonnes untraced ones is equal to $6.27E+05$, which will be the amount effectively represented in the tracing of this study. The percentual change between traced and untraced tonnes is equal to 4.6%.

3.2.2 Comparison of soy equivalent tonnes export data between the CWASI and Trase databases

Trase data for soybean export are referred to equivalent soybean; this means that the recorded tonnes include primary soybean and secondary soybean products, such as oil, cake, sauce, paste and curd. The CWASI database (Tamea et al., 2020) records export, production and virtual water trade volume for single item. In order to validate the reliability of the exported tonnes record between Trase and the CWASI database, CWASI data for primary and secondary soybean products have been converted to equivalent tonnes of soybean. In the work of Mekonnen and Hoekstra (2010) are available the conversion factors for each secondary item reported in table 3.2.2. The ratio between the product fraction P_f and the volume fraction V_f is multiplied by the tonnes recorded in the CWASI database for each secondary product. The equivalent tonnes obtained, see table 3.2.3 are summed to calculate the overall quantity of soybean equivalent tonnes traded between Brazil and Italy in 2016.

Table 3.2.2: Product fraction(P_f) and value fraction (V_f) of soybean products Mekonnen and Hoekstra (2010)

Product	Pf	Vf	Vf/Pf
Soya beans	1.00	1.00	1.00
Soya sauce	3.50	1.00	0.29
Soya curd (tofu)	3.75	1.00	0.27
Soybean ingredient into the soymilk	0.57	1.00	1.75
Soy burger	0.57	1.00	1.75
Soya bean flour and meals	0.85	1.00	1.18
Soya-bean oil crude, whether or not degummed	0.18	0.34	1.91
Soya-bean oil-cake both solid residues,whether or not ground or pellet	0.796	0.66	0.83

Table 3.2.3: Conversion in soy equivalent tonnes for the CWASI database secondary soybean items

Product	Item, FAOSTAT code	Tonnes	Equivalent tonnes of soybean
soybeans	236	$5.19E+05$	$5.19E+05$
oil	237	0	0
cake	238	$1.58E+05$	$1.31E+05$
sauce	239	62	$1.77E+01$
paste	240	0	0
curd	241	missing	missing

The resulting total export of soybean equivalent tonnes for CWASI database is $6.50e+05$. The variation in soy equivalent tonnes export to Italy between Trase and the CWASI database for the year 2016 is of 1%: the results are reasonably comparable. This 1% is due to the lack of data recorded for the item 241, the soya curd, in the CWASI database.

3.3 Footprint assessment: merging the local impact with trade data

The first step after having identified and mapped the productions exported to Italy in 2018 throughout the Brazilian territory, is to use the administrative boundaries of the detected Brazilian municipalities to clip the unitary water footprint data available worldwide for soybean (m^3/tonnes) from Tuninetti et al. (2015), in maps 2.2.1 to the municipalities involved in the production of 2018. In figure 3.3.1 they are represented the two succeeding steps: on the left it is represented the uWF extended over all the Brazilian municipalities producing soybean in 2018, on the right the municipalities producing for the traced Italian import.

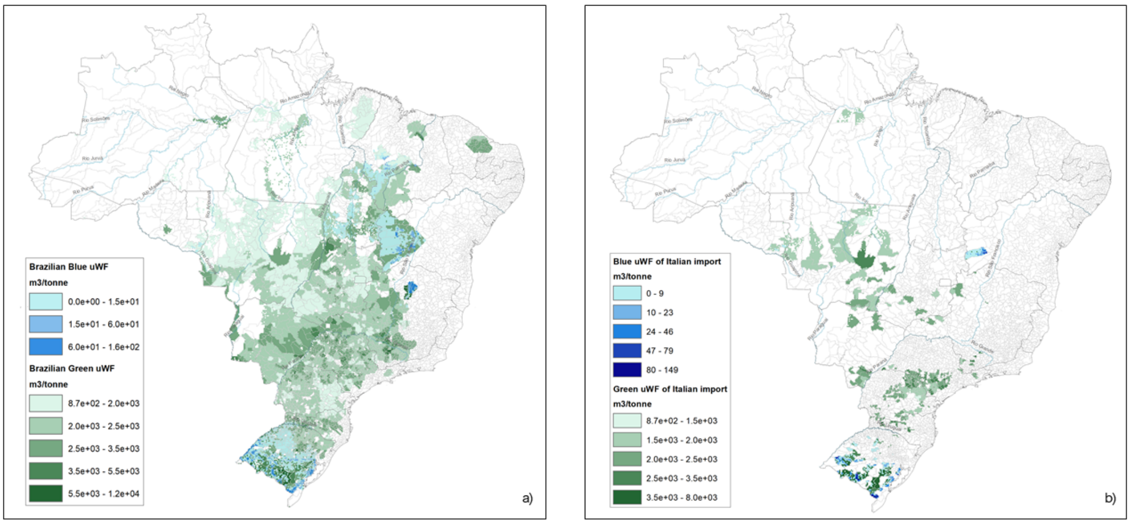

Figure 3.3.1: Brazilian soybean blue and green uWF (Tuninetti et al., 2015) extended over a) all the Brazilian municipalities producing soybean in 2018, b) the municipalities producing for the traced Italian import in 2018 at 5 arc minutes spatial resolution

Then, the raster clipped over the municipalities engaged in the export to Italy in 2018, has been averaged over the area of each municipality, in order to obtain the uWF at the municipality scale, reported in the results of chapter 5. The blue uWF and green uWF have been summed in order to obtain the total uWF at the municipality scale, whose results are shown in chapter chapter 4. The turning point of the method is the merging between the achieved results and the production at the municipality scale obtained through the method explained in section**??**. This calculation has been made for blue and green water footprints. The two of them have been summed to get the total WF at the municipality scale. The merging has resulted in loosing 23 municipalities due to the reason explained in chapter 2: in Appendix Appendix A in table A.0.1 are reported the missed municipalities and the related production.

Having set the WF volumes at the municipality scale, the geography and ecology of production have been investigates, to understand the local dynamics and underpin some environmental issues which may be related to the water footprint assessment either in synergy or opposition at the sub-national scale. Data from literature have been contextualized to assess the production in each federal state, according to the geographical region of Brazil and its production activities. At first, they have been detected the most intense producer municipalities, and observed the distribution of them within the different states and regional areas of Brazil. Data of production have been pivoted on state to identify the rate of production averaging weighing down on each municipality according to the related state. Already at this stage of analysis, it stands out the importance of the regional patterns both in production and trades analysis. In fact, each region and each state are characterized by peculiar features of production and environmental attributes that can be shared by some neighbouring municipalities. Knowing the number of producing municipalities and the cumulative production pf each state toward Italy in 2018, the weighted average of state production over it municipalities has been calculated, to highlight whether the production is intense on a municipality or extended over more municipalities of the state. This information helps to assess the leading trend of production toward Italy.

At this point, in order to assess the WF in relation with the interaction between human activities - specifically the water exploitation and deforestation related to soybean cropland conversion- with ecosystems, it has been elaborated the anthromes mapping of Ellis and Ramankutty (2008), illustrated in chapter **??** in figure **??**.The first passages have been the same lead for the WF calculation: at first, the raster values for municipalities and federal states have been extracted using as masks the administrative areas of municipalities and states, as shown in figure **??**.

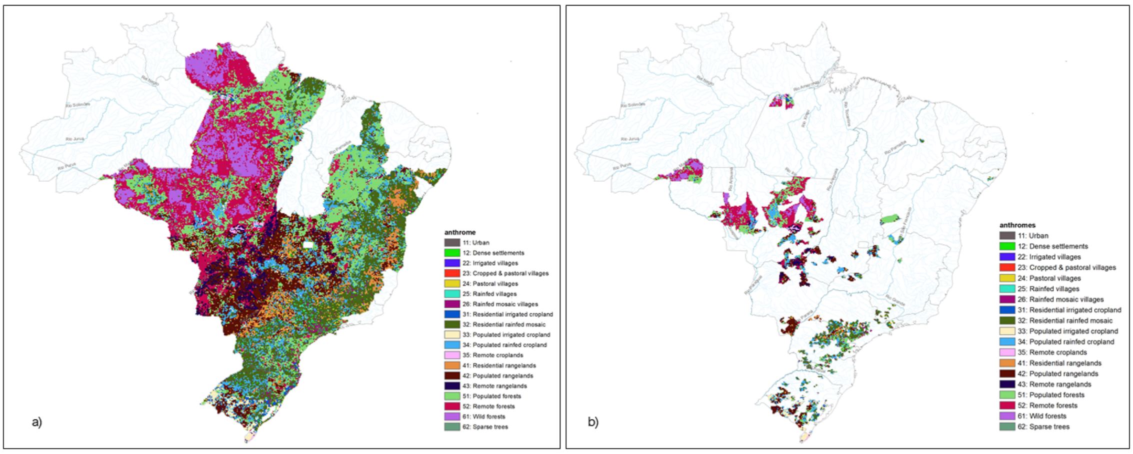

Figure 3.3.2: Raster extraction by mask of Anthromes mapping in order to evaluate the histograms of frequency within the analyzed a) federal states and b) municipalities involved in Italian import in 2018

Then, histograms of frequency have been calculated at three different scales, reporting the histograms in matrices, each row representing the state or the municipality, each column the bin corresponding to a specific anthrome. Two nested cycles counted the maximum value occurring along the row and saved the column index corresponding to the maximum recorded. Specifically, the analysis has been the following:

- Counting of cell values occurring in each federal state to observe the anthrome distribution within the states and the inner percentages of dominance;
- Counting of cell values occurring in each municipality producing soybean for the Italian

import in 2018, in order to identify the prevalent anthrome at the municipality scale detecting the maximum value through the nested cycles;

- Summing along columns the number of cells detected for each classified antrhome in the previous step, in order to quantify the maximum occurrence of each class in the municipalities involved in the production toward Italy in 2018.

Concerning municipalities, it has been significant to detect and map only the maximum value of occurrence, being the municipality the higher spatial resolution scale of the study. A shortcut of the matrix with municipalities histogram values is shown in figure 3.3.3.

Municipality	11	12	22	24	25	26	31	32	33	34	35	41	42	43	51	52	61
Ariquemes	0	0	0	0	0	1	1	3	0	5	0	0	0	0	43	1	0
Cerejeiras	0	0	0	1	0	0	0	0	0	5	0	0	15	1	6	5	1
Corumbiara	0	0	0	0	0	0	0	1	0	2	0	1	9	0	18	2	0
Porto Velho	1	1	0	0	0	1	0	7	0	1	0	0	0	0	55	155	179
Rio Crespo	0	0	0	0	0	0	0	0	0	1	0	0	0	0	13	9	0
Vilhena	0	1	0	0	0	0	0	2	0	4	1	0	0	0	12	64	53
Alto Paraíso	0	0	0	0	0	0	0	1	0	0	0	0	0	0	30	0	0
Candeias do Jamari	0	0	0	0	0	0	0	2	0	0	0	0	0	0	10	31	37
Cujubim	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	27	14
Itapuã do Oeste	0	0	0	0	0	0	0	1	0	0	0	0	0	1	8	32	5
Mojuí dos Campos	0	0	0	0	0	0	4	8	5	2	0	0	0	0	5	27	8
Santarém	1	0	0	0	0	0	6	4	11	20	32	0	1	4	38	69	19
Regeneração	0	0	0	0	0	0	0	9	0	4	0	0	0	0	0	0	0
Anadia	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0
Campo Alegre	0	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0	0
Jundiá	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Junqueiro	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0
São Miguel dos Campos	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
Correntina	0	0	0	0	0	0	0	4	0	8	0	0	6	1	116	2	0
Andradas	0	0	0	0	0	1	0	5	0	0	0	0	0	0	0	0	0
Araguari	0	1	0	1	0	0	0	14	0	11	0	1	7	0	2	0	0
Borda da Mata	0	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
Caldas	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0
Capinópolis	0	0	0	1	0	0	0	2	0	4	0	1	0	0	0	0	0
Careaçu	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Conceição dos Ouros	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Extrema	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Januária	0	0	0	0	0	1	0	14	0	40	0	0	0	0	28	0	0
Jequitaí	0	0	0	0	0	0	0	1	0	2	0	0	1	0	10	0	0
Lavras	0	0	0	2	0	0	0	4	0	0	0	0	0	0	0	0	0
Monte Alegre de Minas	0	0	0	1	0	0	0	0	0	6	0	0	27	0	0	0	0
Poços de Caldas	0	1	0	0	0	2	0	5	0	0	0	0	0	0	0	0	0
Santa Rita do Sapucaí	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0
São Gonçalo do Sapucaí	0	0	0	0	0	1	0	6	0	0	0	0	0	0	0	0	0

Figure 3.3.3: Matrix reporting for each muncipality the histogram of frequency of anthromes classes, where each anthrome - identified by a numeric code along the header row- is a bin high as much as the number of its occurrence within the municipality, reported as cell values. The maximum of each row is identified as the dominant anthrome within the municipality, corresponding to a column position equal to the anthrome class.

With regards to states instead, the bins' distributions have been represented with pie charts overlaid to each federal state, in order to illustrate the heterogeneity of anthromes revealed but, mainly, to observe either the dominance of a main anthrome or a quite homogeneity of distribution among the classes within each state. The matrix obtained for states is reported as example in figure 3.3.4.

State	11	12	22	23	24	25	26	31	32	33	34	35	41	42	43	51	52	61	62
Acre	1	1	0	0	1	0	0	1	38	1	28	3	1	1	0	513	980	369	0
Alagoas	2	1	0	0	13	24	10	12	219	0	0	0	51	0	0	0	0	0	0
Amapá	1	0	0	0	0	0	1	0	57	0	12	1	0	4	0	325	1074	187	0
Amazonas	4	2	0	0	0	0	4	7	140	3	33	9	0	1	6	1996	9264	6865	0
Bahia	5	12	0	0	18	2	37	33	2481	5	1039	3	605	326	45	1949	201	0	0
Ceará	4	4	0	2	0	3	24	24	1368	0	169	0	115	19	0	20	0	0	0
Distrito Federal	6	9	0	0	0	0	5	0	43	0	11	0	0	0	0	1	0	0	0
Espírito Santo	5	7	0	0	14	1	10	3	359	0	42	0	81	24	0	25	0	0	0
Goiás	6	14	0	0	48	1	7	7	209	29	558	8	364	1860	288	522	214	0	0
Maranhão	3	2	0	0	6	0	19	23	1403	16	671	5	104	80	8	1331	196	0	0
Mato Grosso	3	1	0	0	12	1	13	2	205	30	648	119	82	1052	541	2178	4873	1066	1
Mato Grosso do Sul	1	7	0	0	24	1	2	1	46	5	211	2	102	2167	874	253	751	0	3
Minas Gerais	23	28	0	0	115	1	80	19	2238	18	1081	5	902	1439	108	1048	118	0	0
Pará	4	5	0	0	5	0	11	26	791	31	539	52	63	267	29	3800	5337	3611	3
Paraíba	1	3	0	1	16	13	18	9	360	1	29	0	189	19	0	2	0	0	0
Paraná	16	24	0	0	27	19	55	12	1081	15	497	2	245	144	1	362	57	2	0
Pernambuco	5	9	0	0	28	36	46	15	683	6	129	0	131	26	0	43	0	0	0
Piauí	2	1	0	0	0	0	7	4	734	3	461	10	28	43	0	1521	154	0	0
Rio de Janeiro	29	25	0	0	15	2	42	9	255	3	28	0	86	10	0	39	6	0	0
Rio Grande do Norte	2	3	0	1	3	3	16	13	350	0	40	0	164	22	0	5	0	0	0
Rio Grande do Sul	18	33	0	0	27	16	66	190	984	540	703	23	117	594	19	289	48	0	0
Rondônia	1	5	0	0	7	0	6	2	136	0	171	2	37	59	3	760	1049	587	1
Roraima	0	1	0	0	3	0	1	0	19	1	10	7	0	138	72	190	864	1297	9
Santa Catarina	8	16	0	0	4	6	85	44	550	9	141	4	30	18	0	292	43	1	0
São Paulo	61	76	1	0	76	65	152	38	1082	4	410	1	551	304	0	266	45	0	0
Sergipe	2	1	0	0	17	0	7	6	119	0	1	0	109	0	0	0	0	0	0
Tocantins	0	0	0	0	4	0	2	2	152	13	265	55	104	825	115	1213	542	2	0

Figure 3.3.4: Matrix reporting for each federal state the histogram of frequency of anthromes classes, where each anthrome - identified by a numeric code along the header row- is a bin high as much as the number of its occurrence within the state, reported as cell values. The maximum of each row is identified as the dominant anthrome within the state, corresponding to a column position equal to the anthrome class.

The third point has been calculated counting the frequency of each anthrome in being the most prevalent one at the municipality scale throughout the Italian Import, as illustrated in 3.3.1

Table 3.3.1: Cumulated frequency of the anthromes' classes identified in the cells within the area of the municipalities involved in the Italian import in 2018 along the all municipalities analyzed

Anthrobiome	**cells**
11: Urban	10
12: Dense settlements	27
22: Irrigated villages	1
24: Pastoral villages	46
25: Rainfed villages	12
26: Rainfed mosaic villages	75
31: Residential irrigated cropland	64
32: Residential rainfed mosaic	925
33: Populated irrigated cropland	286
34: Populated rainfed cropland	1079
35: Remote croplands	88
41: Residential rangelands	185
42: Populated rangelands	1125
43: Remote rangelands	270
51: Populated forests	1477
52: Remote forests	1993
61: Wild forests	565
62: Sparse trees	7

Once revealed the prevalent anthrome at the state and municipality scale, these results have been compared with the outcomes of the WF assessment. The anthromes mapping of Ellis and Ramankutty (2008) relies on productions and harvested land mapped in Monfreda et al. (2008), in figure 2.3.2 and in figure 2.3.1, as well as Tuninetti et al. (2015), in figure **??** which referred to the year 2000. The mapping of Monfreda et al. (2008) provides the highest spatial resolution available in literature for agricultural productions, 5 arc minutes. Consequently, the changing in land use occurred in the last 20 years, are missed. The comparison of the WF volumes obtained with the production of the year 2018, with the anthromes mapped referring to passed rates of production, makes possible to underpin the changes and assume the current classification of anthropogenic biomes, specifically for the Italian import. In chapter **??** within the results, in figure **??** is illustrated the expected regression of anthromes over time, according to the definition of ecological succession by Smith and Smith. The regression has been built observing the contrast among volumes of WF calculated for the production of 2018 and the anthrome laid in the background referred to year 2000. The regression starts from the wilder anthropogenic biomes, proceedings to more harvested anthrobiomes, according to the classification of Ellis and Ramankutty reported in chapter chapter 2, throughout the agricultural expansion (ha) and the intensification of production ($tonnes/ha/year$) (FAOSTAT, a) over time. The anthromes regression comes along with the born and size-changing of water footprint volumes (m^3) involved: they are identified qualitatively through correlation between deforestation (Trase, 2020), (Trase, 2018b), (European Space Agency) and the alteration of the hydrological cycle, (Leite-Filho et al., 2019), the water exploitation increasing for irrigation (Pousa et al., 2019), (ANA, 2017) and the results obtained in the study.

3.4 Virtual water trade: the Italian supply-chain

This part of the method pivots the analysis on the trader companies WF assessment and works on two levels of analysis: the sub-national impact assessment of production and and the national allocation of the utilization supply of the importer country. The two scales allows to connect the production's impact to the final outcome, in order to provide instrument to companies or governance to act whether the impact assessment highlights some characteristics environmentally at issue.

3.4.1 Sub-national trade flows to link the Italian consumer

This block starts by the Trase elaboration data output, numbered as (4) in the flow diagram in figure 3.0.1. Summing along columns the matrix in table **??** in Appendix A it is possible to obtain the cumulative production of engaged trader companies over the year 2018. At this point, the analysis proceeds at a detailed scale for the major exporting companies, resulting Bianchini, Cofco, Bunge, Cargill, Louis Dreyfus and Amaggi. With the aim of building the bipartite network of WF connecting their engaged municipalities and the importer country, at step (16). At first, the information pivoted on companies are spatially analyzed on GIS and joined with the municipalities

uWF shapefile - obtained in the step numbered as (7) in 3.0.1. This step allows to associate the municipalities and their relatives attribute such as production, uWF, biome and anthrome to the companies holding their export flow to Italy in 2018. The tables reporting the listing of municipalities and the calculated attributes are illustrated in the Appendix B Appendix C, Appendix D, Appendix E, Appendix F and Appendix G. This passage allows also to consequently evaluate the water-efficiency at the company scale and to understand the grade of variation of the water-efficiency between municipalities which production are handled by the same trader company. To proceed in this analysis, the cumulative frequency curve of the uWF along the municipalities engaged is built for each exporter group in study; the boxplot representation is the best suitable for observing the distribution of values around references set values, such as reference quantiles, the median and the weighted average. Thus, hereafter are illustrated the passages implemented: it is presented as example the set of operations made for the Amaggi company, while in Appendix C, Appendix D, Appendix E, Appendix F and Appendix G are reported the curves of distribution obtained for the other five companies, namely Bianchini, Bunge, Cargill, Cofco, Louis Dreyfus. Table 3.4.1 illustrates how the curve of cumulated frequency is built: at first municipalities are sorted in ascending order of uWF, then the cumulated production of the i-th municipality of the array is calculated as:

$$Prod_{cum}(i) = \Sigma_{k=1}^{i} Prod_k \tag{3.4.1}$$

where:

- N is the total number of municipalities in the array;
- $Prod_{cum}(i)$ is the relative frequency of the production carried in the i-th municipality of the array containing the municipalities engaged in the production of the company, along with their production and the total uWF

The percentage frequency is then:

$$Prod_{perc}(i) = (\Sigma_{k=1}^{i} Prod_k / \Sigma_{k=1}^{N} Prod_k)100 \tag{3.4.2}$$

being $\Sigma_{k=1}^{N} Prod_k$ the total production summed over the N municipalities

Table 3.4.1: Table structure to build the cumulative curve frequency of uWF along the municipalities involved in the production

municipality (-)	uWF ($m^3/tonnes$)	Prod ($tonnes$)	$Prod_{cum}$ ($tonnes$)	$Prod_{perc}$ (%)
CEREJEIRAS	1.64E+03	2.72E+03	2.72E+03	11.5
CORUMBIARA	1.73E+03	2.27E+03	4.99E+03	21.1
PORTO VELHO	1.76E+03	1.13E+03	6.13E+03	25.9
VILHENA	1.81E+03	1.99E+03	8.11E+03	34.4
BRASNORTE	1.83E+03	2.50E+03	1.06E+04	45.0
CAMPO NOVO DO PARECIS	1.88E+03	4.50E+03	1.51E+04	64.0
COMODORO	1.89E+03	1.34E+01	1.51E+04	64.1
SAPEZAL	1.90E+03	8.48E+03	2.36E+04	100.0

In figure 3.4.1 is reported the curve obtained for the Amaggi company.

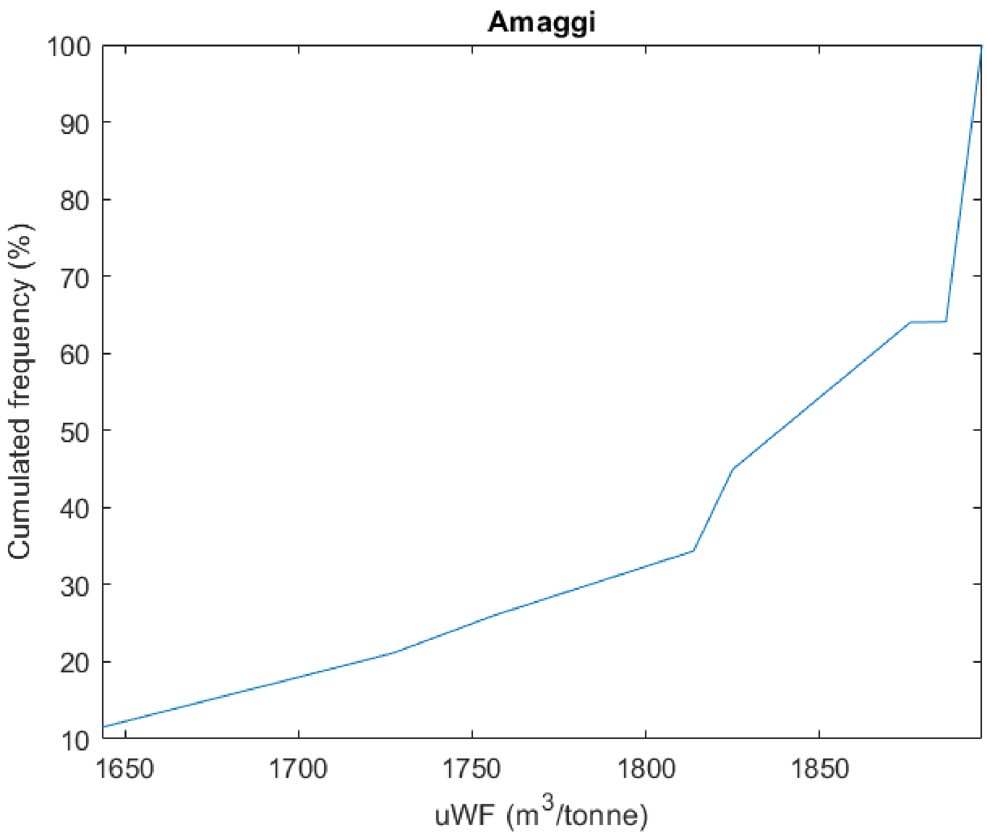

Figure 3.4.1: Curve of relative cumulated frequency of uWF over Amaggi's sourcing production

Still, being the objective to represent comparatively the curve of distribution of the uWF of the six analyzed companies, the percentile relative to the reference quantiles 10%, 25%, 50%, 75%,90% of production are linearly interpolated through the Matlab function *interp1* which returns interpolated values of a 1-D function at specific query points. Setting as query points the reference quantile, they are obtained the percentile of the 10%, 25%, 50%, 75%, 90% of production. The example for the Amaggi company is represented below in figure 3.4.2.

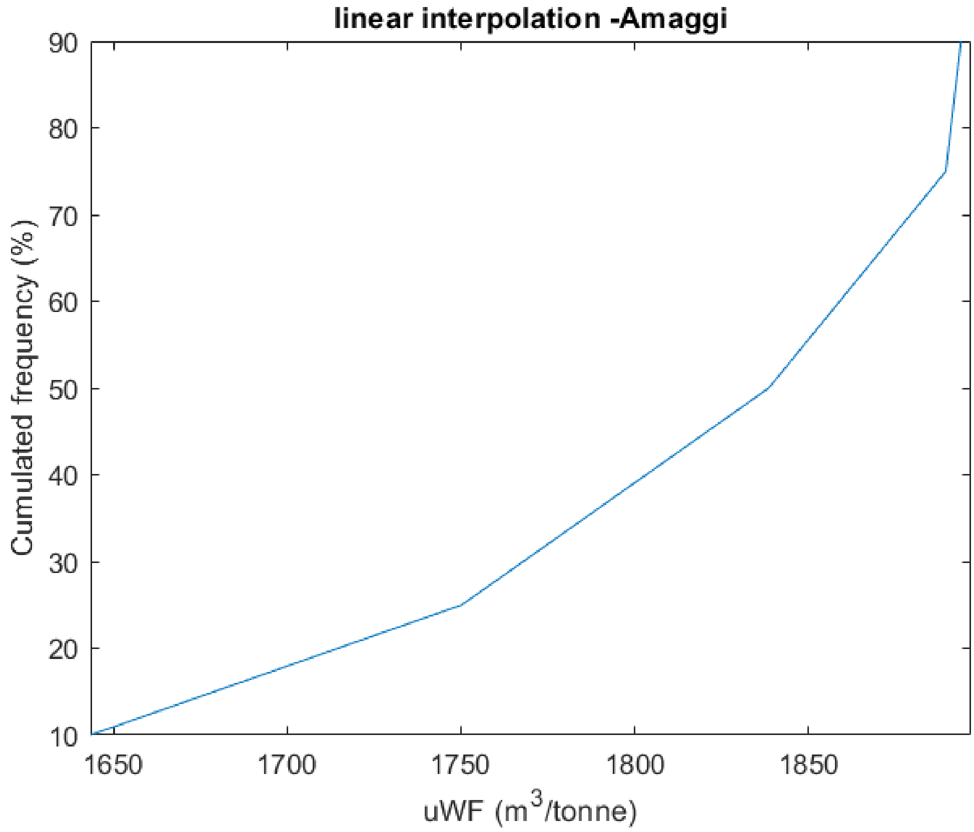

Figure 3.4.2: Linearly interpolated curve of relative cumulated frequency of uWF over Amaggi's sourcing production for the quantiles of production 10%, 25%, 50%, 75%, 90%

The other value considered for the comparative analysis of companies water efficiency is the weighted average of uWF, calculated as:

$$uWF_{wa} = \Sigma_{i=1}^{N}(uWF_i Prod_i)/\Sigma_{i=1}^{N} Prod_i \tag{3.4.3}$$

To best assess the comparison among companies, in the boxplot representation it is assigned to each company an identification RGB triplette, respectively:

- color= [222 0 0, 121 135 72, 179 0 89, 214 71 212, 231 108 7, 29 68 184]/255;

sorted descending according to the array:

- order='Cargill','Cofco','Amaggi', 'Bunge' ,'Louis Dreyfus','Bianchini'

The color palette will be utilized from this point on for all the comparative representations regarding companies. The order series is chosen according to the geographical distribution of companies emerged from the previous GIS spatial analysis: from the companies operating in the northernmost latitudes to that operating in southrernmost ones. Further, in order to assess whether the water efficiency among the municipalities engaged by each company is driven by the Y_a or by $ET_{a,y}$ the yields mapped in Monfreda et al. (2008) are investigated, being the uWF defined in Tuninetti et al. (2015), as in equation (2.2.1)

The factor 10 in (2.2.1) converts the evapotranspired water height expressed in mm into a water volume per land surface expressed in m^3/ha.

Thus, the uWF, being the ratio between the water evapotranspired by the crop during the growing seasons of a year y, $ET_{a,y}$ (mm), and the crop actual yield, Y_a $(tonnes/ha)$ is determined by the two dimensions ET_a or Y_a.

The process to evaluate the yields at the municipality scale includes the same raster calculation implementated fot uWF data - mapped as well at 5 arc minutes spatial resolution worldwide. The yield values averaged at the municipality scale are thus made available and joined with the attributes of production, uWF, biome and anthrobiome, associated to the municipalities involved in the companies' trading. The averaged yields at the municipality scale are reported in Appendix B Appendix C, Appendix D, Appendix E, Appendix F and Appendix G. Likewise the water-efficiency analysis, the first step necessary to evaluate the yield variation over companies' sourcing production is to calculate for each company the curve of relative cumulated frequency of yield values over productions. The example for Amaggi is here reported in figure 3.4.3 and figure 3.4.4, while the curves for the other companies are reported in Appendix B Appendix C, Appendix D, Appendix E, Appendix F and Appendix G.

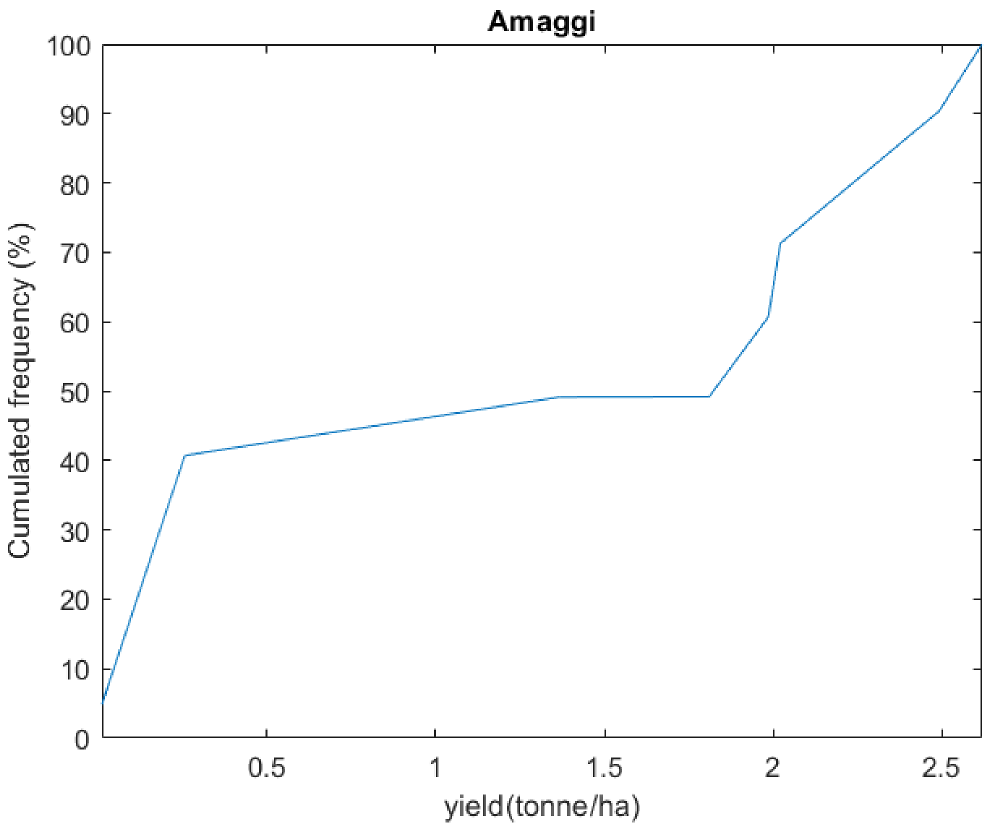

Figure 3.4.3: Curve of relative cumulated frequency of yield $(tonnes/ha)$ over Amaggi's sourcing production

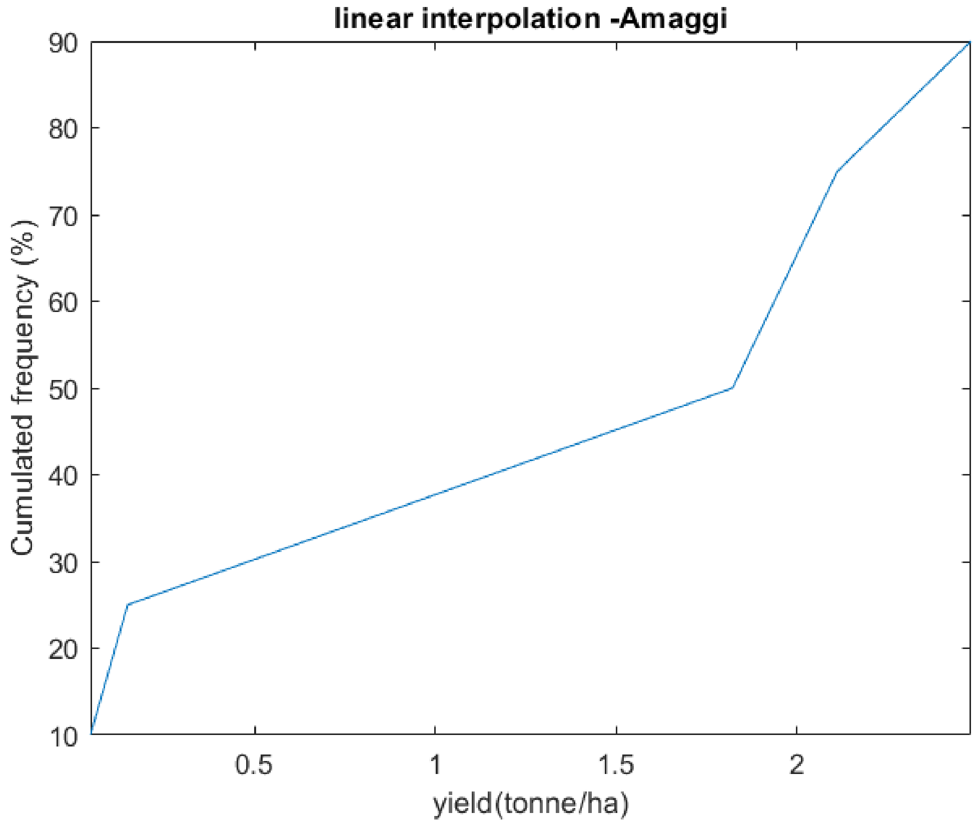

Figure 3.4.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Amaggi's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

The evapotranspiration is the combined phenomenon of evaporation of water from soil and vegetation, and of transpiration of water through plant's leaves' stomas. The evapotranspiration of a crop according to the method proposed by Allen et al. (1998) is defined as:

$$ET_c = ET_0 \cdot k_c \qquad \left(\frac{mm}{d}\right) \tag{3.4.4}$$

where:

ET_0 is the evapotranspiration of a standard reference surface, calculated trough the Pennman-Monteith equation (Allen et al., 1998):

$$\lambda \cdot ET = \frac{\delta \cdot (R_n G) + \rho \cdot C_p \cdot \frac{(e_s e_a)}{r_a}}{\delta + \gamma \cdot (1 + \frac{r_s}{r_a}} \tag{3.4.5}$$

- λ: latent heat of vaporization (MJ/m^2);
- δ: saturated vapor gradient at temperature T_a, (P_a/C);
- R_n: net radiation ($MJ/m^2/d$);
- G: heat flux transferrd to the soil ($MJ/m^2/d$);

- ρ average air density at constant pressure;
- C_p: specific air heat at constant pressure, assumed to be 1013 $(J/kg/K)$;
- e_a: actual vapour pressure at a reference altitude z, (P_a);
- e_s: saturated water vapor pressure, (P_a);
- γ : psychrometric costant, (P_a/C);
- r_s: resistance to flux taking into account the characteristics of soil and of the vegetation canopy, calculated as $200/L$, where L is the areal index of the leaf;
- $L = 24 \cdot hc$; hc minimum crop height;
- r_a: aerodynamic resistance, (s/m).

The ET_0 quantifies the potential evapotranspiration of water, depending only on climate conditions-such as temperature, humidity, solar radiation and wind velocity- and not by the specific land use. The k_c crop factor is the percentage of evapotranspiration of the specif crop, with respect to the ET_0 of the standard surface. Still, the boundary conditions of the ET_c are optimal irrigation, and absence of plant diseases. The k_s reduction factor is introduced to adjust the ET_c when soil characteristics are not optimal to allow the crop to evapotranspire completely: this coefficient embodies the effect of the water stress on crop transpiration.

$$ET_a = ET_0 \cdot k_c \cdot k_s \qquad (mm/d) \tag{3.4.6}$$

In this study, the kind of evapotranspiration considered is the ET_a, function of:

- management, which includes the timing of sowing and harvesting, the way, quantity and timing of irrigation;
- crop characteristics;
- climatic characteristics.

The evapotranspiration spatial variability throughout production is taken into account to complete the analysis on company water-efficiency, in the light of the curves of cumulated relative frequency of uWF and *yields* throughout production. The ET_a at study, being referred to the reference year 2000, is the $ET_{a,y}$, the ET_a over the growing season of a year. Depending on agricultural practices, climate and soil properties, the crop evapotranspires green $(ET_{g,y})$ and/or blue water $(ET_{b,y})$ (Tuninetti et al., 2015). Thus, the total water evapotranspired by the crop during the growing seasons of a year is:

$$ET_{a,y} = ET_{g,y} \cdot ET_{b,y} \tag{3.4.7}$$

Thus, prior, the study analyzes the two components $ET_{b,y}$ and $ET_{g,y}$, in figure 3.4.5 then the spatial variability of the total $ET_{a,y}$ is discussed in chapter 4

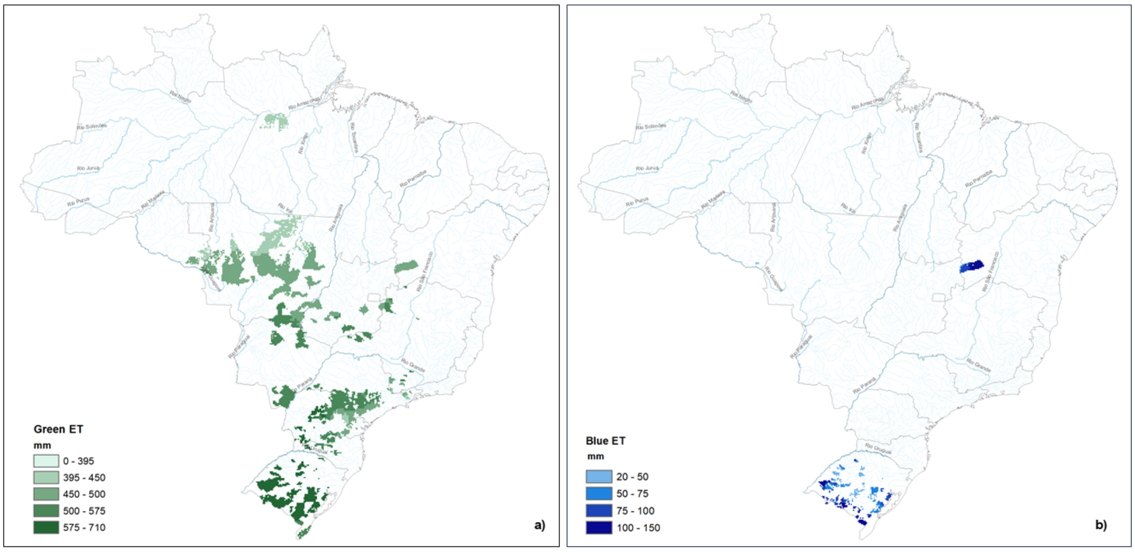

Figure 3.4.5: Green and blue evapotranspiration of the yearly growing season throughout the municipalities sourcing the Italian supply in 2018, at 5 arc minutes resolution, with reference year 2000 (Tuninetti et al., 2015)

The contribution of geography and climatic patterns in determining the water-efficiency between companies' supplies on the Brazilian country, is studied thus calculating the weighted average latitudes of their sourcing productions. In ArcGis, the (X, Y) coordinates are generated for each municipality of each company. The working Reference System is the WGS 84 - EPSG: 4326, thus the latitude and longitude coordinates are projected on the WGS 84 reference ellipsoid.The ArcGis environment expresses the (X, Y) coordinates, respectively longitude and latitude, in decimal grades. The weighted average centroid of production (X_{med}, Y_{med}) for each company is calculated as:

$$X_{med} = \frac{\sum_{i=1}^{N} X_i \cdot Prod_i}{\sum_{i=1}^{N} Prod_i} \tag{3.4.8}$$

$$Y_{med} = \frac{\sum_{i=1}^{N} Y_i \cdot Prod_i}{\sum_{i=1}^{N} Prod_i} \tag{3.4.9}$$

Where i is the index counting the municipalities along the municipalities' array of each company's attribute table. Latitudes and longitude obtained are converted from decimal degrees to degrees minutes and assigned to each company, the procedure for the latitude conversion is illustrated in figure 3.4.6

```
load('X_med.mat');
load('Y_med.mat');
lat=struct2cell(Y_med);
lat=cell2mat(lat);
lat=sort(lat,'descend');

minuti=nan(6,1);
latitudine=table('Size',[6 3],'VariableNames', {'gradi','minuti','secondi'}, 'VariableTypes',{'double','double','double'});
latitudine.Properties.RowNames = {'Amaggi','Bianchini','Bunge','Cargill', 'Cofco', 'Louis Dreyfus'};
for i=1:6
    latitudine.gradi(i)=fix(lat(i));
    minuti(i)=abs(latitudine.gradi(i)-lat(i))*60;
    latitudine.minuti(i)=fix(minuti(i));
    latitudine.secondi(i)=abs(latitudine.minuti(i)-minuti(i))*60;
    latitudine.secondi(i) = round(latitudine.secondi(i),0);
end

lat_geo=strings(6,1);

simbolo_gradi='°';
simbolo_minuti="'";
simbolo_secondi='''';
emisfero='S';
latitudine.gradi=abs(latitudine.gradi);
latitudine.gradi=string(latitudine.gradi);
latitudine.minuti=string(latitudine.minuti);
latitudine.secondi=string(latitudine.secondi);

latitudine=table2array(latitudine);
for i=1:6
    %lat_geo(i)=append(latitudine.gradi(i),simbolo_gradi,latitudine.minuti(i),simbolo_minuti,latitudine.secondi(i),simbolo_secondi,emisfero);
    lat_geo(i)=append(latitudine(i,1),simbolo_gradi,' ',latitudine(i,2),simbolo_minuti,' ',latitudine(i,3),simbolo_secondi,'  ',emisfero);
end
```

Figure 3.4.6: Conversion procedure of latitudes from decimal degrees into degrees minutes and attribution to relatives company in an only attribute table.

The following step is the merging of uWF data ($m^3/tonnes$)- *blue*, *green* and *total*- at the municipality scale with the traced *tonnes* of production per municipality handle by a specific company at study. The merging procedure is the same lead for the yearly production at the municipality scale, but it is lead distinctly for the six analyzed top-trading companies, characterized by a vector$[uWF]_c$ and by another one $[Prod_{2018}]_c$:

$$[WF]_c = [uWF]_c \times [Prod_{2018}]_c \tag{3.4.10}$$

The WF volumes related to each municipality listed in the the companies' attribute table, are summed to obtain the yearly WF_{yc} volume per company as:

$$WF_{yc} = \sum_{i=1}^{N} WF_i \qquad (m^3) \tag{3.4.11}$$

where

- $WF_{y,c}$ is the WF volume of a company over the year;
- WF_i is the i-th WF of the analyzed company in the i-th municipality of its sourcing list;
- N is the total number of municipalities supplying the company over the year.

The data limitation discussed in **??** cause the loss of 25 municipalities itemized in A.0.1 in Appendix A; some of them belong to the trading operation of the analyzed companies as here reported in **??** in Appendix A

The $WF_c, 2018$ of each company is analyzed among its *blue* or *green* water component; the summarized values over the year 2018 in (3.4.11) are connected in a bipartite network between the sourcing nodes - the traced municipalities - through the handling of trading companies analyzed- to the importer country. The bipartite graph is really suitable to model networks with matched connections. It is defined as a graph whose vertices can be divided into two disjoint and independent sets $\{U\}$ and $\{V\}$ such that every edge connects a vertex in$\{U\}$ to one in $\{V\}$. Vertex sets $\{U\}$ and $\{V\}$ are usually called the parts of the graph (Asratian et al., 1998). In this study the bipartite network is actually composed by a two couple-sets. The first two parts of the graphs, setting up the first matching couple, are the traced producing municipalities, $\{U\}$ and the exporter groups $\{V\}$ at study. This matched connection ends up in a new one between $\{V\}$ and the importer country, that can be named as the set $\{W\}$, as in figure 3.4.7

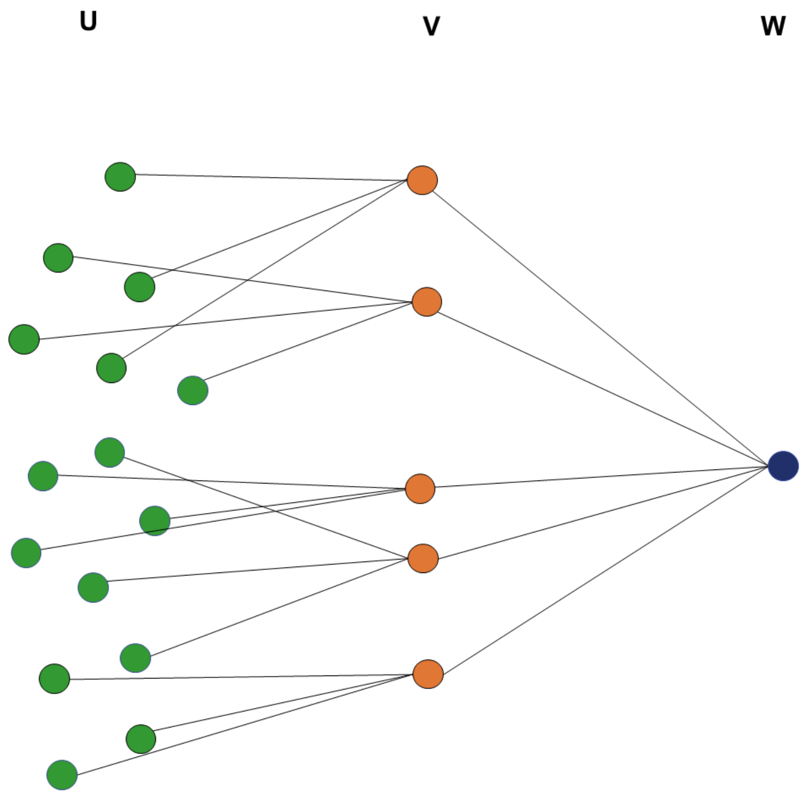

Figure 3.4.7: Bipartite graph connecting municipalities to companies and companies to importer country

3.4.2 Food Balance Sheets to assess the final utilization of imported soybean

This step of analysis works on relating the imported commodity to the utilization possibilities of the importer supply. It is possible to imagine this step as the fourth part of the double-bipartite graph in figure 3.4.7, finalising the graph as schematized in following figure 3.4.8, adding the set $\{Z\}$ to the network supply.

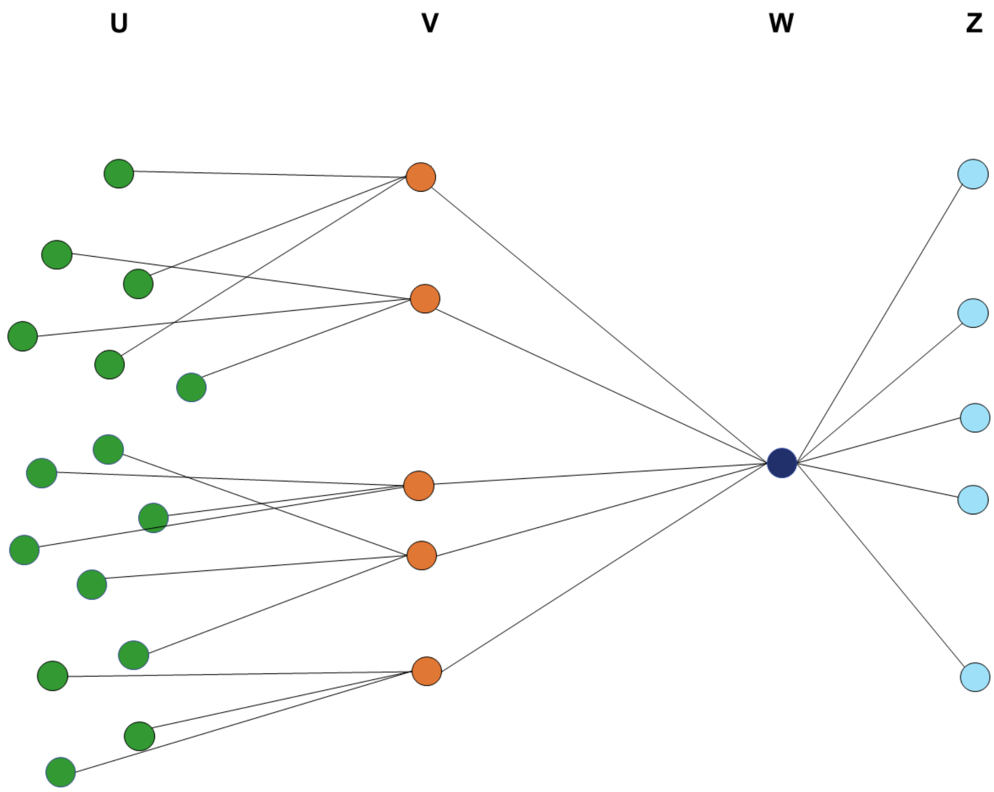

Figure 3.4.8: Bipartite graph with four nodes, connecting municipalities to companies- companies to importer country-importer country to supply utilization possibilities

The new Food Balance Sheet from FAOSTAT (b) makes available the blocks of allocation at country scale. Data, available since 21^{st} of January 2021, are sourced for Italian Soybean supply. The food balance sheet shows for each food item - i.e. each primary commodity and a number of processed commodities potentially available for human consumption - the sources of supply and its utilization. The FBS is analyzed for soybean in 2018- where soybean supply utilization accounts are soya beans, soya sauce, soya paste, soya curd (FAOSTAT, FBS and USA list). Among the possible elements, the non zero values for the Italian FBS in 2018 results:

- Production
- Import Quantity;
- Stock Variation;
- Export Quantity;
- Domestic supply quantity;
- Feed;
- Seed;
- Losses;
- Processing;

- Food;
- Food supply quantity (kg/capita/yr;
- Food supply (kcal/capita/day);
- Protein supply quantity (g/capita/day).

While are found null the following values:

- Residuals;
- Food supply (kcal/capita/day);
- Fat supply quantity (g/capita/day).

The element of interest to build the set of the network in 3.4.8 are all the itemized except for Food supply quantity (kg/capita/yr, Food supply (kcal/capita/day), Protein supply quantity (g/capita/day), Food supply (kcal/capita/day), Fat supply quantity(g/capita/day); being these relevant more for a nutritional evaluation of the national supply balance. Though, the low values of this elements for the study case of Italy, 3.4.2 suggest a small nutritional contribution in the human direct consumption as food in the supply.

Table 3.4.2: Nutritional elements of the New FBS for the Italian soybean supply in 2018 compared to those of other grain staple crops such as Wheat, Rice, Maize and Oats from FAOSTAT (b) in the year 2018

Element	**Value**	$Value_{Wheat}$	$Value_{Rice}$	$Value_{Maize}$	$Value_{Oats}$
Food supply quantity (kg/capita/yr)	0.04	145.56	8.39	4.46	0.22
Food supply (kcal/capita/day)	0	1035	58	34	2
Protein supply quantity (g/capita/day)	0.01	32.62	1.13	0.78	0.09
Fat supply quantity (g/capita/day)	0	3.84	0.11	0.11	0.04

The path from supply input to utilization blocks can be summarized as follow in figure 3.4.9. The import and production concur to fill the input supply; when addressing to the output of the supply, this can be named as utilization. In order to identify the quantity of the commodity in question which is available for utilization within the country, according to FAO (2001) is adopted the balance in (3.4.12) to define what in this study is referred as *utilization*:

$$production + imports \pm stocks = supply\, for\, export\, and\; domestic\, utilization. \tag{3.4.12}$$

The element $\pm stocks$ is given as negative, to fill the utilization inner balance. The other possible definitions of supply, following the Handbook compound by FAO (2001) are:

$$production + imports - stocks = total\, supply \tag{3.4.13}$$

$$production + imports - exports \pm stocks = supply\, for\, domestic\, utilization \tag{3.4.14}$$

Equation (3.4.14), with negative sign for *stock*, quantifies what in this work is defined as the *Italian utilization* or *Italian Domestic supply*, while differently from (3.4.13) this works refers to the *Total Supply* or simply *Supply* as:

$$total\,supply = import + production \tag{3.4.15}$$

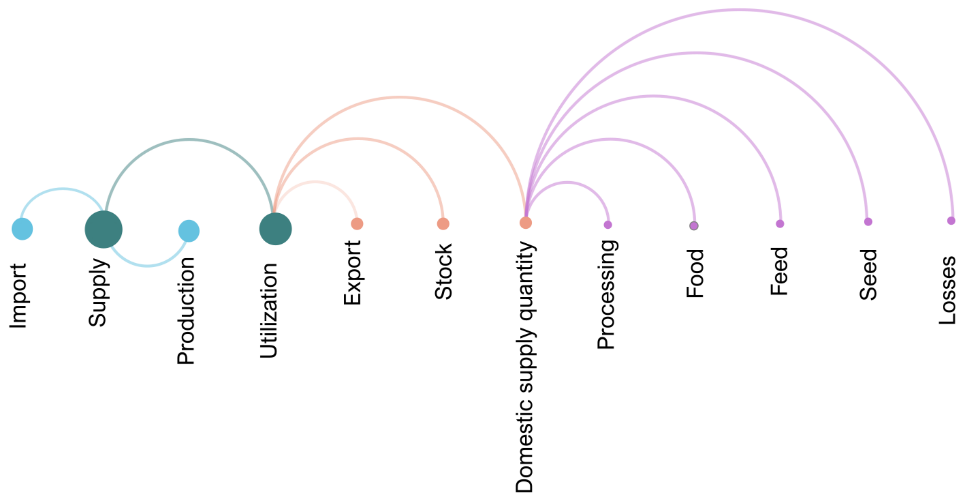

Figure 3.4.9: Construction of the Italian soybean supply path of 2018 for the elements of interest included in the Food balance Sheet FAOSTAT (b)

The element *Losses* is collocated among the Domestic Supply possibilities, as a result of the inner balance of this block:

$$Domestic\,supply\,quantity = Processing + Food + Feed + Seed - Losses \tag{3.4.16}$$

In order to connect 3.4.9 to the trader companies' set $\{V\}$ and obtaining the set $\{Z\}$ the trade information by Trase are incorporated in the import block of the FBS. At the bottom of the utilization supply, the FAO element 'Processing' can be still expanded. From FAOSTAT (a) it is possible to source the production quantities of primary and processed products at the national scale for the year of interest. In the case study of Italy, the only processed product available in 2018 is the soybean oil, thus, being the soybean cake the other by-product produced FAOSTAT (a), the amount of soybean cake is obtained as:

$$Soybean\,cake = Processing - Soybean\,oil \tag{3.4.17}$$

These element are added at the top and bottom of the supply chain in figure 3.4.9 obtaining the set in figure 3.4.10, representing the closing connections of the double bipartite network in figure 3.4.8

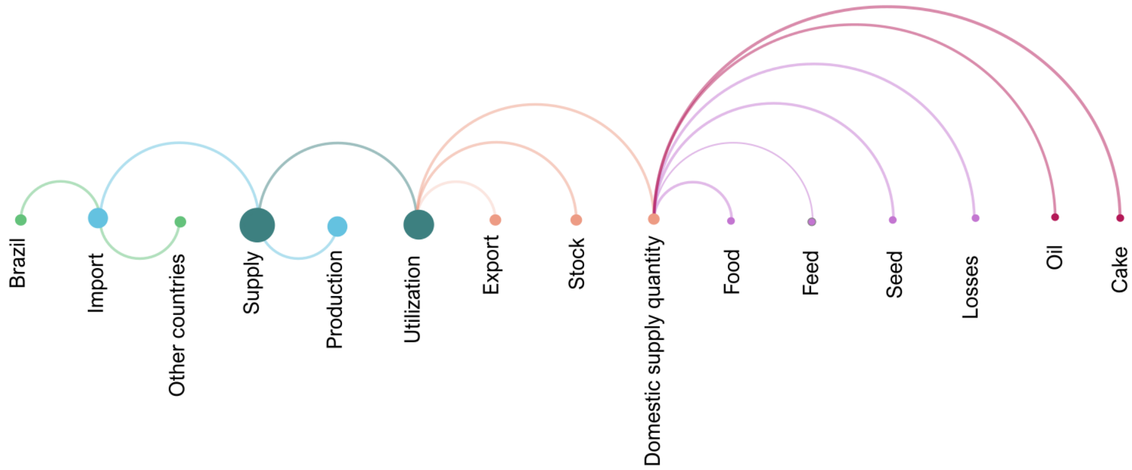

Figure 3.4.10: Construction of the Italian soybean supply path of 2018 recurring to the elements of interest included in the Food Balance Sheet FAOSTAT (b), Production Sheets of 2018 from FAOSTAT (a) and Trase data for 2018

At this point, the set $\{U\}$ can be directly connected to the set $\{Z\}$, proportionally allocating the weight of the utilization items of the Italian supply to the WF volumes obtained at the company's scale. Each company of the set $\{V\}$ presents an extension over the municipalities in $\{U\}$ and a weight in the input of set$\{W\}$. Since the FBS refers to soya beans and other edible soybean products but no to soybean oil or soybean cake, (FAOSTAT, b); this study considers two separate paths to allocate either soybean import or processed soybean import. From FAOSTAT (c) Italian import of soybean oil from Brazil results null, thus it is consider just the additional path of soybean cake already processed and imported in the Italian supply. Therefore, at first, analyzing the Italian import from Brazil of respectively, primary soybean and cake in 2018 the proportion between the two is considered to assess the percentage of either soybean or cake flowing from the traced municipalities through the major six companies analyzed. From FAOSTAT (c), in 2018:

Table 3.4.3: Itlian import from Brazil of primary soybean and soybean cake in 2018, in primary soybean equivalent tonnes FAOSTAT (c)

Soybean import (*tonnes*)	Soybean Cake import (*tonnes*)
267610	205567

Thus, to the primary soybean is allocated the 57% of the Italian soybean equivalent total import from Brazil, to the soybean cake the 43%. The 3.03e+05 tonnes detected from the all traced municipalities are unbundled among the two possibilities: 1.73 e+05 tonnes of imported primary soybean and 1.30e+05 tonnes of imported soybean cake.

At this point, the resulting equivalent tonnes of primary soybean are placed as input in the Italian FBS. It is calculated the weight of the six major companies with respect to the total primary soybean trade from Brazilian municipalities, obtaining an array with six percentages of weight, $[company_w]$. Alongside, it is filled an array $[item_w]$ reporting the weights of the five utilization items identified in the Italian domestic supply: 'oil', 'cake', 'food', 'feed', 'seed'. By multiplying the two arrays as:

$$[WF_{all}]_{5\times6} = [item_w] \times [company_w] \cdot [WF]_{c,y} \tag{3.4.18}$$

where $[WF_{all}]_{5\times6}$ is the WF allocated among the five items ending the FBS, for the six companies weighted on the Brazilian import.

Regarding the allocation of the WF of companies within the Italian import of cake, likewise the primary soybean case, it is calculated the weight of each analyzed company in the trade, compiling a second array $[company_w]_cake$.

$$[WF_{all_{cake}}] = [companies_w]_{cake} \cdot [WF]_{c,y} \tag{3.4.19}$$

The $[WF_{all_{cake}}]$, resulting as an array $[5\times$
$]$ is summed to the row related to soybean cake in $[WF_{5\times6}]$. The final $[WF_{5\times6}]$ matrix is imported in GIS as an attribute table to be joined with the geographical features of the companies, through the array of companies' weighted centroids of sourcing production.

As a final step, the Italian current production of soybean is investigated. The climatic potential yield and the yield gaps for the year 2000 described in chapter chapter 2 are elaborated in ArcGIS at the Italian provinces' scale. Already in 2000 the yield gap of the North-East regions results closed, thus the related provinces are exlued from the analysis, which aims at detecting possible ranges of yield improvement to boost the Italian domestic supply of soybean. The spatial resolution is set by the agricultural census of ISTAT. From this statistics data-set, which estimation methodology is explained in chapter **??**, they are sourced the yearly productions- gave in (*quintals*) - and the harvested areas (*ha*) of the most recent years: 2018,2019,2020. Specifically, ISTAT provides both the total production and the harvested production: the harvested production is the quantity considered to calculate the yearly yields of the provinces. The obtained matrices are exported in ArcGis and processed by joyining the obtined features with the Italian administritive boundaries.

Chapter 4

Results

The methodology developed in this study enabled to evaluate the supplier production of soybean for Italy at the sub-national scale and to quantify the associated water footprint volumes flowing from Brazilian municipalities in the year 2018. Additionally, it made possible to detect the volumes associated to the trader companies and to link them to the utilization patterns of the Italian domestic supply.

The chapter is divided in four sections:

- the first one is dedicated to the results obtained with the processing of Trase data concerning the quantities, the geography and the ecology of production at the sub-national scale;
- the second section reports the results obtained by the merging of the processed results with unitary water footprint data, evaluating the virtual water flows at the municipality scale;
- the third illustrates the results obtained at the company's scale;
- the fourth shows the allocation weights of the examined water footprint in the Italian domestic supply.

The first three results come out from the output obtained by the pre-proccesing method discussed in chapter 3 which can be read from two different point of views. At first, it is possible to focus on the yearly volume flowing from a specific municipality toward Italy in 2018 aggregating the tonnes produced by each detected company in a municipality over the entire year, allowing the identification of the major sources of water flow per year. Secondly, the method enables to stuck on the exporter companies and analyze the water footprint volumes incoming to Italy in 2018 and to detect their geographical local domain. In the latest section of the chapter it is presented the allocation of the imported virtual water flow in the Italian national supply, which has been possible merging the results of the previous three sections with the updated Food Balance sheet by

FAOSTAT, as detailed in chapter 3.

The water footprint volumes obtained at the municipality scale and at the company's scale are represented in thematic maps; the results of the virtual water trade at the company's scale are outlined in a bipartite network from the municipalities of production-through the exporting companies- to Italy. The variability of the production and of the unitary water footprint values and of the resulting water footprint volumes at the sub-national scale are examined and discussed. The allocation is discussed and represented through a Sankey diagram, an Alluvial graph and two histograms series. A final map merge the outcomes of the third and fourth results.

4.1 Production at the municipality scale

In this section are reported the results concerning the first set of objectives of this study: assessing the the supplier production for Italy at the sub-national scale in 2018. The processing algorithm developed as been run for Italy and for other six main European importers from Brazil, according to Trase: Spain, Netherlands, Germany, France, United Kingdom, Denmark and Norway. These results are illustrated in Appendix H and suggest interesting comparisons with the Italian supply import. Along with Trase data processing, geography has been considered at first, due to the resolute spatial scale of study, which requires a deep understanding of the local patterns. Thus, figure 4.1.1 shows the regional areas of Brazil and the administrative divisions in federal states.

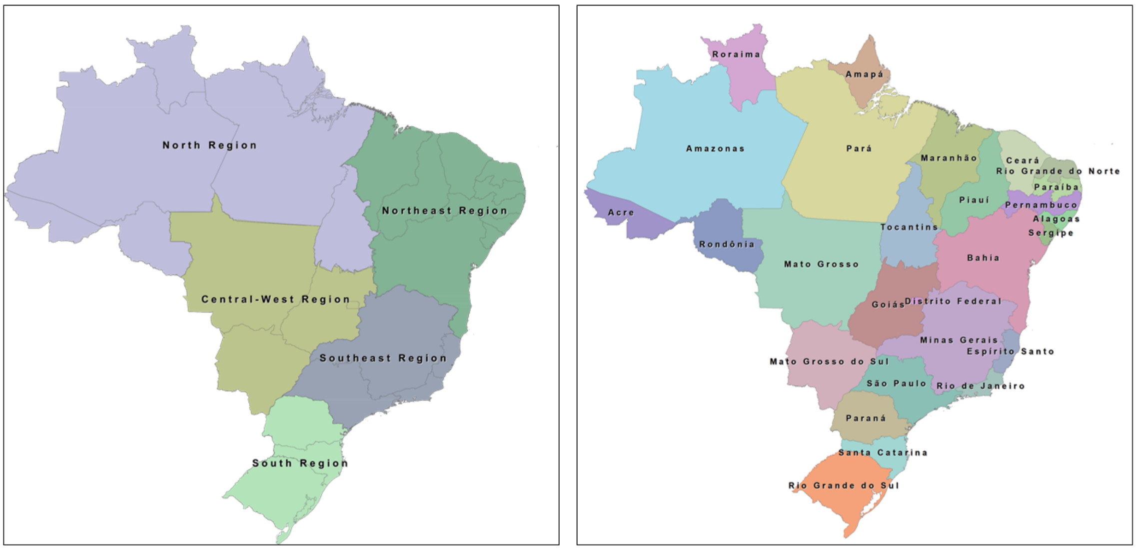

Figure 4.1.1: Geographic framework of Brazil

As a first result, from the output table in Appendix A it emerges that Italy supplies from 374 Brazilian municipalities, extended quite widely throughout the Brazilian country, as shown in the map in figure 4.1.2, which reports the production collected over the year 2018 in each municipality.

The color ramp highlights that the most intensive centres of production are focused in the Central-West and in the South regions while some spots are displaced in the North and Central-East regions.

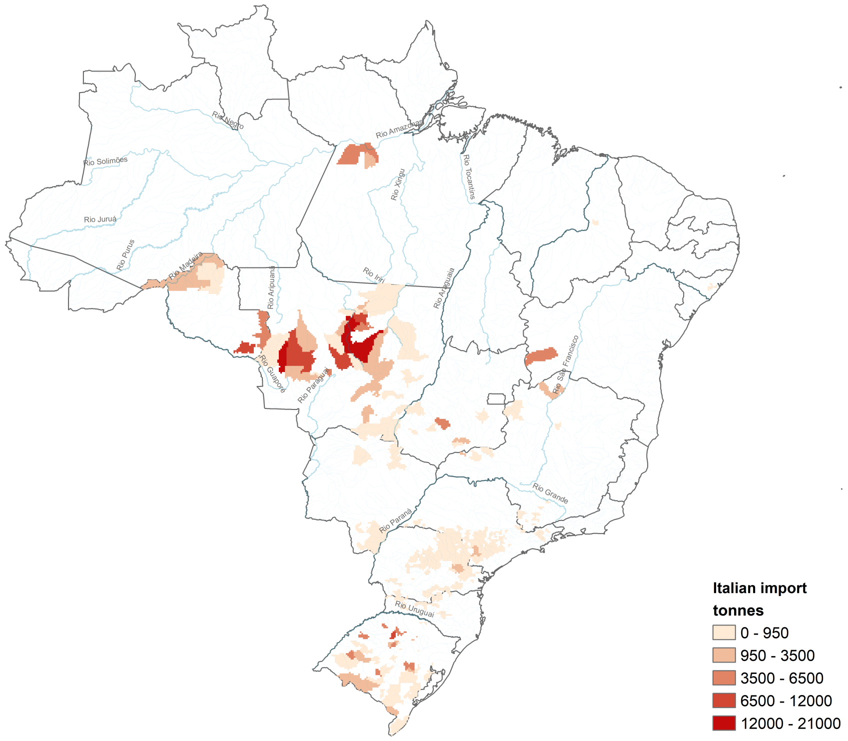

Figure 4.1.2: Italian import of soybean from Brazilian municipalities in 2018

Table 4.1.1 reports the major producer municipalities and points out that these are several in Mato Grosso and Rio Grande do Sul, while few but with intense production in the states of Rondônia, Pará, Goiás and Bahia. The first supplier of Italy is the municipality of Sorriso in Mato Grosso, Central-west region, with its $2.08e+04 tonnes$ provided along the year. The total traced supply amounts to $3.03e+05 tonnes$, first ten suppliers provide the 39% of the Italian import analyzed, the first thirty the 72%.

Table 4.1.1: First thirty producer municipalities for Italian import in 2018

State (-)	**Municipality** (-)	**Production** (*tonnes*)
Mato Grosso	Sorriso	2.08E+04
Mato Grosso	Campos de Júlio	1.68E+04
Mato Grosso	Nova Ubiratã	1.52E+04
Mato Grosso	Sinop	1.51E+04
Rio Grande do Sul	Santa Bárbara do Sul	1.14E+04
Mato Grosso	Nova Mutum	1.13E+04
Mato Grosso	Sapezal	1.04E+04
Mato Grosso	Campo Novo do Parecis	8.50E+03
Mato Grosso	Cláudia	7.92E+03
Rondônia	Cerejeiras	7.89E+03
Rondônia	Corumbiara	6.60E+03
Rondônia	Vilhena	6.32E+03
Rio Grande do Sul	Carazinho	6.21E+03
Rio Grande do Sul	Fortaleza dos Valos	5.84E+03
Pará	Santarém	5.72E+03
Rio Grande do Sul	Rio Pardo	5.72E+03
Rio Grande do Sul	Chapada	5.53E+03
Rio Grande do Sul	Santo Augusto	5.15E+03
Mato Grosso	Nortelândia	5.13E+03
Goiás	Paraúna	5.07E+03
Mato Grosso	Santa Carmem	4.89E+03
Rio Grande do Sul	Manoel Viana	4.55E+03
Bahia	Correntina	3.86E+03
Rio Grande do Sul	Santa Margarida do Sul	3.81E+03
Rio Grande do Sul	São Luiz Gonzaga	3.72E+03
Rio Grande do Sul	Sant'Ana do Livramento	3.29E+03
Rio Grande do Sul	Camargo	3.06E+03
Mato Grosso	Rondonópolis	2.79E+03
Mato Grosso	Ipiranga do Norte	2.75E+03
Rio Grande do Sul	Jaguarão	2.75E+03

Table 4.1.1 leads though to a state-level analysis, suggesting a different engagement of municipalities in each federal state of the country.

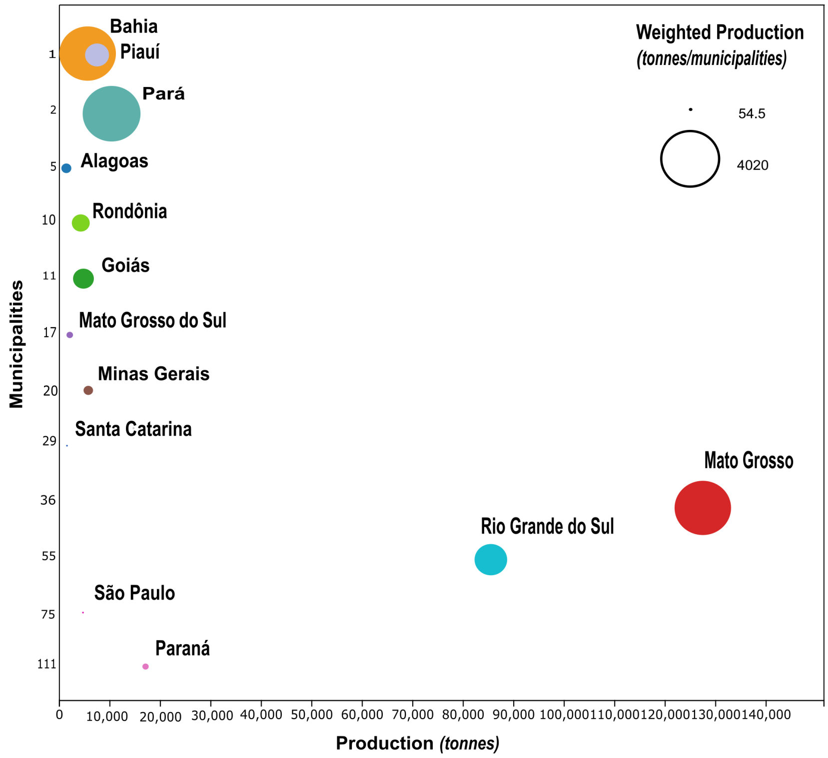

Figure 4.1.3: Weighted production of Brazilian States involved in Italian soybean import in 2018. For each state the number of municipalities involved in the soybean production are shown on the y-axis. The bouble's size is proportional to the average production typical of the municipality in each state. The color scheme distinguishes the federal states

The graph in figure 4.1.3 reports the production toward Italy that characterizes each state: the X axis represents the tonnes collected in 2018, the Y axis the number of municipalities where production is located while the size of the bubble expresses the average production of a municipality in each state. Mato Grosso and Rio Grande do Sul stand out as the biggest producers as observed already from table 4.1.1; what is interesting to notice is that Bahia and Pará figure out to be the states where municipalities have the highest intensity of production. The matching between figure 4.1.3 and table 4.1.2 reveals that Pará, with two municipalities and an average of 4020 *tonnes/municipality*, has the highest average of production per municipality, followed by Bahia with one municipality and 3860 *tonnes/municipality* and by Mato Grosso, with 36 municipalities committed and 3850 *tonnes/municipality* produced. States where productions are concentrated in few municipalities are: Piauí, Alagoas, Rondônia and Goiás. In contrast, the productions of Rio Grande do Sul, of Paraná and of São Paulo are clearly mitigated by the contribution of respectively 55, 111 and 75 municipalities, showing a production likely extended throughout the territory. Mato Grosso do Sul, Minas Gerais and Santa Catarina are quite smoothed by a significant number of municipalities engaged, with respect to the amount of their production.

Table 4.1.2: Comparison between production and average production per municipality of each state involved in soybean production toward Italy

State (-)	**Production** (*tonnes*)	**Municipalities** (-)	**Weighted Production** (*tonnes/municipalities*)
Mato Grosso	1.39E+05	36	3.85E+03
Rio Grande do Sul	8.21E+04	55	1.49E+03
Paraná	1.81E+04	111	1.63E+02
Pará	8.04E+03	2	4.02E+03
Goiás	8.03E+03	11	7.30E+02
Rondônia	5.84E+03	10	5.84E+02
São Paulo	5.22E+03	75	6.97E+01
Minas Gerais	5.06E+03	20	2.53E+02
Bahia	3.86E+03	1	3.86E+03
Mato Grosso do Sul	2.88E+03	17	1.69E+02
Santa Catarina	1.58E+03	29	5.45E+01
Alagoas	1.34E+03	5	2.68E+02
Piauí	8.91E+02	1	8.91E+02

The results obtain concerning the biomes involved in the production toward Italy in 2018 are shown in figure **??**.

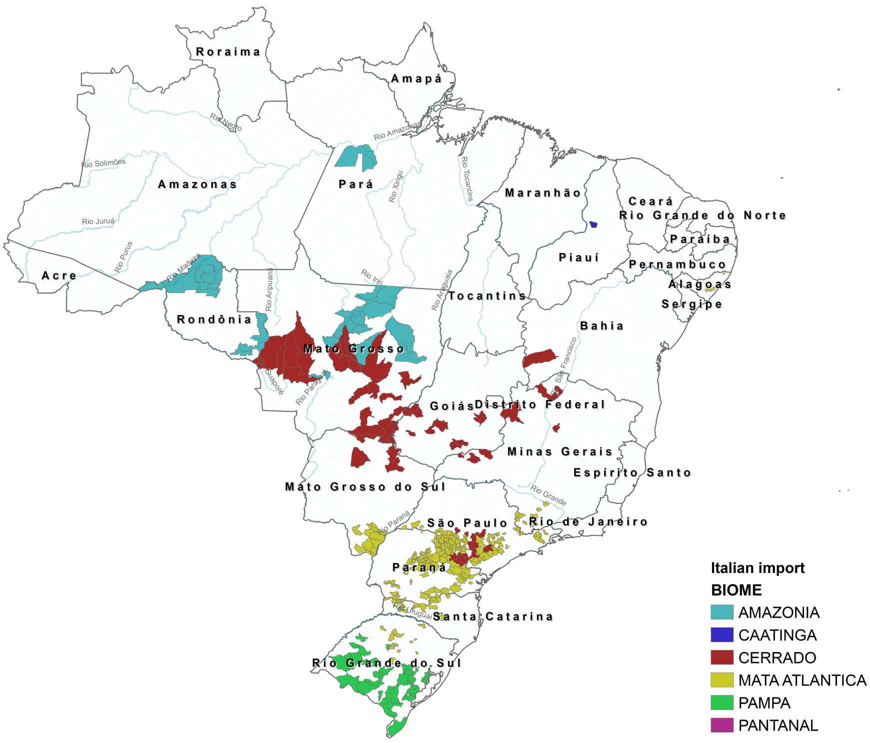

Figure 4.1.4: Biomes involved in Italian soybean import in 2018 from sourcing municipalities

Among the six biomes present in Brazil- Amazon Forest, Caatinga, Cerrado, Pampa and Pantanal- Italian import sources from all except from Pantanal. Table **??** illustrates for each biome which are the states involved in the Italian supply. What stands out in the table is that Mata Atlantica and Cerrado belong both to eight states and that the states with the highest production rates are located in Amazonia (Rondônia, Pará, Mato Grosso), Cerrado (Mato Grosso, Bahia, Goiás) and in Mata Atlantica and Pampa (Rio Grande do Sul).

Table 4.1.3: Biomes of Brazilian States involved in soybean production toward Italy in 2018

Biome	**State**
Amazonia	Rondônia Pará Mato Grosso
Caatinga	Piauí
Cerrado	Piauí Bahia Minas Gerais São Paulo Paraná Mato Grosso do Sul Mato Grosso Goiás
Mata Atlantica	Alagoas Minas Gerais São Paulo Paraná Santa Catarina Mato Grosso do Sul Goiás Rio Grande do Sul
Pampa	Rio Grande do Sul

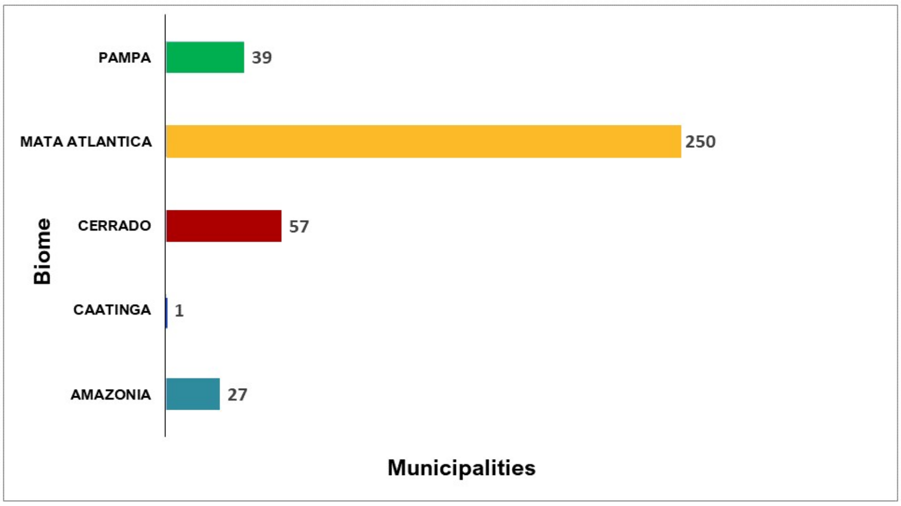

Figure 4.1.5: Number of municipalities running soybean production toward Italy in 2018 per each biome involved

Figure 4.1.5 shows that the highest number of municipalities leading soybean export to Italy is located in Mata Atlantica, then in Cerrado and in the Amazon. This result matches with the one in figure 4.1.3: the states located in Mata Atlantica, such as Santa Catarina, São Paulo, Paraná, and in part Rio Grande do Sul, are characterized by expanded productions throughout their municipalities, reporting a smoothed intensity of the average production over each municipality. Conversely, states in the Amazon and Cerrado such as Pará, Piauí, Rondônia, Bahia, Goiás and Mato Grosso tend to have concentrated productions toward Italy, being extended over a lower number of municipalities, with respect to the amount of soybean supplied per year.

4.1.1 Biomes and land use

Figure 4.1.6: Biomes of Brazil according to IBGE, MapBiomas (2019)

Biome	Area (Mha, %)	Land Cover	Predominant Land Use
Amazon	419 (49.29%)	Evergreen forest, with enclaves of savanna, natural grassland, and extensive wetlands and surface water, with almost 20% of the forested areas biome cleared.	Cattle ranching, agriculture, mining, logging and non-timber forestry production.
Atlantic Forest	111 (13.04%)	Isolated forest fragments covering 7–10% of the biome, mostly old secondary growth, surrounded by croplands, pasture, forest plantation, urban and infrastructure.	Agriculture, cattle ranching, urban, forest plantation, artificial water reservoir.
Caatinga	84 (9.92%)	Woody and deciduous forests, with at least 50% of the original converted.	Agriculture, cattle ranching, smallholder livestock production, non-timber forestry, and urbanization.
Cerrado	203 (23.92%)	Mosaic of savannas, grasslands and forests, 50% of the native vegetation cover has already been converted.	Agriculture, cattle ranching, artificial water reservoir and timber exploitation for coal production.
Pampa	17 (2.07%)	Natural grassland (Campos), with scattered shrub and trees, rock outcrop formations.	Agriculture, livestock production (in natural grasslands), forest plantation, and urbanization.
Pantanal	17 (1.76%)	Savanna, grassland and wetland.	Agriculture and cattle ranching.

Figure 4.1.7: Biomes of Brazil, classification and land use, Souza et al. (2020)

Both Mata Atlantica and Pampa are biomes that have been altering for a quite long time until today, Mata Atlantica is considered to be over exploited since the begining of European colonialism in Brazil in the VI century, (Morellato and Haddad, 2000). Moreover, Mata Atlantica and the grasslands of Pampa have been the centers of the agricultural colonization of the IX and XX centuries: Santa Catarina, Sao Paulo and Minas Gerais, located in Mata Atlantica, and Rio Grande do Sul, between Mata Atlantica and Pampa were the frontiers of european agricultural colonization. Especially in Rio Grande do Sul the incentives of the Brazil government in the IX and XX centuries to enhance immigration from Europe, in order to secure incoming workforce for agriculture and to populate available land, were embraced by Italian citizens due to a social crisis spreading in rural areas of the country, especially in the North, around 1875. Cultural patterns, such as religion, social structure of the community and geographic features made the Italian colonization of Rio Grande do Sul particularly prosperous for the local development along the years (MAECI, 2008). Nowadays this connection is likely still proven in trade, as Rio Grande do Sul is one of the major sources of the Italian supply for soybean, differently from the trend concerning the majority of the other European importers as shown in the maps of Appendix H. Over all, according to the latest agronomic census (IBGE, 2017) the production of soybean of Rio Grande do Sul, reaching 17.3e+06 *tonnes* in that year, is the second of the country, just after that of Mato Grosso. Mato Grosso is the core of Brazilian soybean production, accounting for 29.8 e+06 *tonnes* of the national production in 2017, (IBGE, 2017) In recent years, this state has been facing an exponential conversion of natural land into croplands, especially for soybean (Trase, 2020). Trase initiative has estimated the clearing of land in this state between 2012 and 2017 to be around 1.7 million *ha* - equivalent to twice the size of London per year- involving for the 16% the Cerrado and for the 31% the Amazon. Moreover, in these years their analysis revealed that the 97% of this deforestation was illegal and directly connected to soybean farms Trase (2020). Differently from Rio Grande do Sul, Mato Grosso is a common source of all main European importer countries, as pointed out by the maps in Appendix H. As reported in table 4.1.3 Mato Grosso is located along the transition between the Amazon Forest and the Cerrado tropical savanna, reason which make this land conversion toward agriculture particularly threatening for biodiversity conservation.

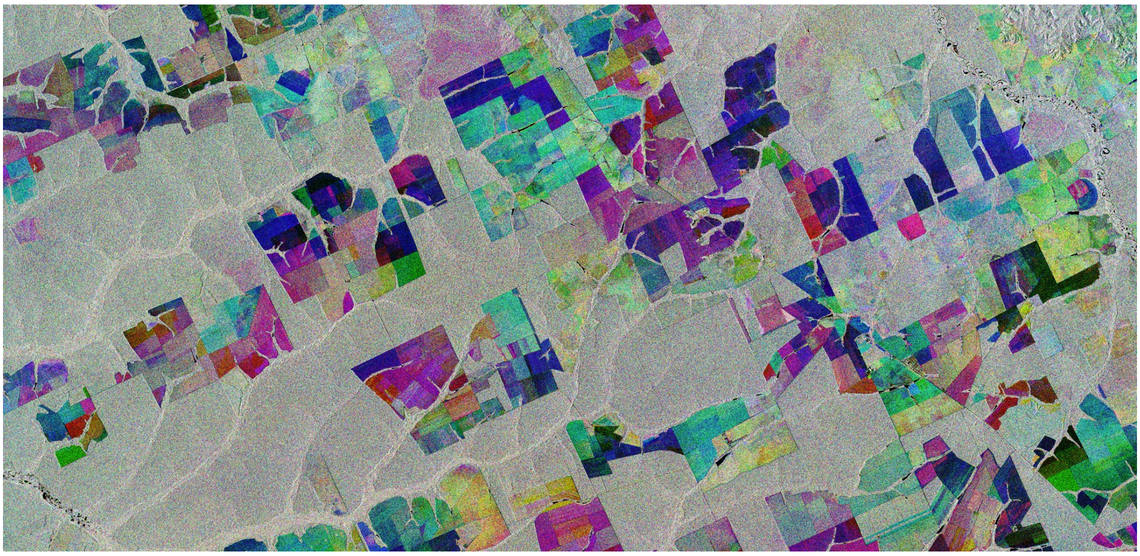

Figure 4.1.8: This image combines three separate radar images from the Copernicus Sentinel-1 mission. The first image, from 2 May 2015, is picked out in blue; the second, from 16 March 2017, picks out changes in green; and the third from 18 March 2019 in red; areas in grey depict little or no change between 2015 and 2019, ESA

At the north-west frontier of Mato Grosso it is located the state of Rondônia. As can be seen from the map in figure 4.1.4, it is deeply nestled in the Amazon Forest, though some municipalities emerge to be among the highest producers of soybean to Italy per year, as shown in table 4.1.3. The amount of production results to be quite similar between Rondônia's municipalities, suggesting that this production may be lead similarly. Differently from the areas of the southern Mata Atlantica and especially of Pampa, historically addressed to agriculture, the intensive agriculture in this area is quite recent: the European Space Agency, with the Copernicus program, has detected 24 years of deforestation from 1986 to 2010, as shown in figure 4.1.9. Since 2010 the clearing of forest for the agricultural expansion continued rising in this area (MapBiomas, 2019).

Figure 4.1.9: Copernicus survey over years, land use change in Rondônia from 1986 since 2010,ESA

Leite-Filho et al. correlated the delay of precipitation onset and the higher duration of dry spells in southern Amazonia with deforesation: the study, includes the state of Rondônia, northern Mato Grosso, and southwestern Pará. Their method, based on land use change and precipitation time series between 1974 and 2012, underlines that: the combination of the delay of the onset with the increasing of the dry spells duration raises the climate risk for agriculture. Higher dry spells duration generates dryer soils and the delay of the onset affects the moisture availability in soil, a requirement fundamental in each development stage of the crop.

The image in figure 4.1.10, has been captured by Sentinel-2A in 2016 over central-eastern Brazil: it corresponds to the west side of the municipality of Correntina, in Bahia state, at the frontier with the states of Tocantis and Goiás. As shown in table 4.1.1 and in figure 4.1.3, Correntina is the only traced municipality in the state of Bahia supplying soybean for Italy, having provided 3.06e+03 *tonnes* in 2018. This area is characterized by a large, flat plateau rich of water, as the name "Correntina" suggests. Correntina is located along some of the tributaries of Rio São Francisco, which, in recent years, is undergoing a decreasing of the flow rate, both in the dry and in the rainy season Pousa et al. (2019). The land use-change survey by the European Space Agency in figure 4.1.10 points out the distribution throughout the area of the pivot systems for irrigation. The west side of Bahia state stands out among other Brazilian states, where land conversion to croplands have been expanding in last years, for its irrigation spreading rate: accounting for 9 pivots in 1985 and 1550 in 2016 (Pousa et al., 2019). From 2006 to 2015, the irrigated land increased of the 61%, and it is expected to grow for 2030, with a variation major than the 100% in this region (ANA, 2017). Table 4.1.3 shows that Bahia state is located in Cerrado, along with part of Mato Grosso State. Production here is quite at issue, being the Cerrado an important and threatened tropical savanna, (Overbeck et al., 2015). It covers 2 million km^2, the 21 (%) of the country's territory, the being the second largest vegetation type in Brazil after the Amazon forest: the area is equivalent to the size of England, France, Germany, Italy and Spain combined. It's one of the richest ecosystem on earth in biodiversity but, despite its environmental importance, it is one of the least protected regions in Brazil: only 20 (%) of its original vegetation remains intact; less than 3 (%) of the area is currently protected by law. By 2030, the Cerrado is projected to lose tens of millions of additional acres of native vegetation. This area is also where the three major water resources of Brazil and (of the entire South America) begin: Rio Amazonas, Rio Paraná-Paraguay, Rio São Francisco, (WWF).

Figure 4.1.10: Pivot systems of irrigation in Bahia captured by Copernicus Sentinel 2A on 8 August 2016, ESA

4.1.2 Anthropogenic biomes

By merging the anthropogenic biomes mapped by Ellis and Ramankutty in 2008 with the Italian import in 2018 from Trase, as explained in chapter 3, it has been possible to detect how the Italian import influences the anthromes already generated by the interaction between human and natural ecosystems. In figure 4.1.11 it emerges that the 49% of the Italian supply, in 2018, sourced from lands where the prelevant anthromes were classified as remote forests (24%), populated forest (18%) and wild forest (7%).

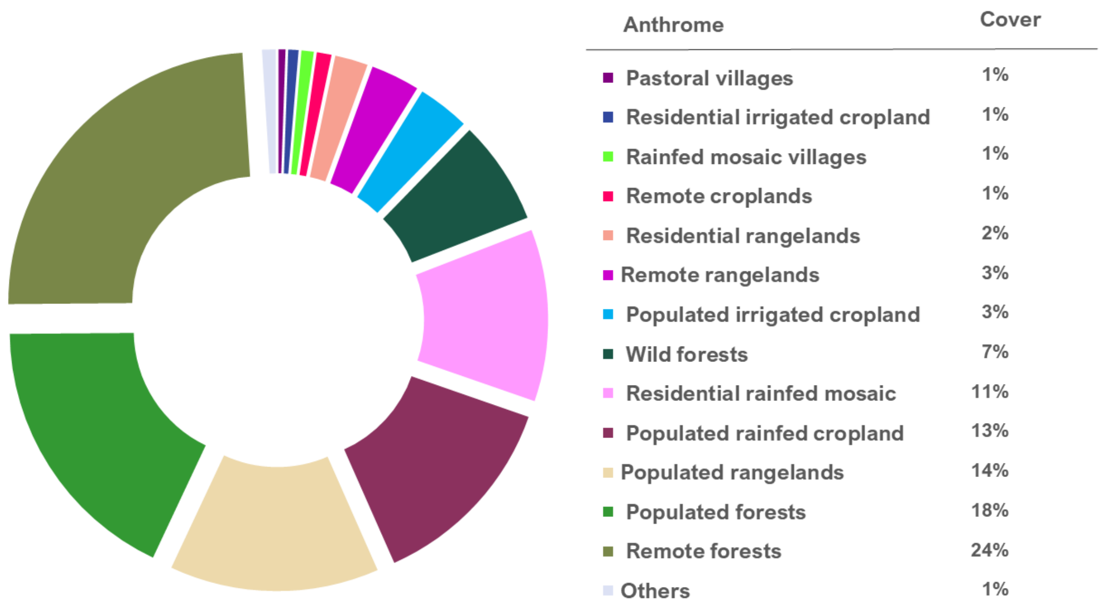

Figure 4.1.11: Anthropogenic biomes involved in soybean production toward Italy in 2018

Table 4.1.4 illustrates which are the percentage of cover of the anthromes defined by Ellis and Ramankutty

Table 4.1.4: Anthrobiomes distributions over Italian soybean import from Brazil in 2018

Anthrobiome (-)	**Cover** (%)
Remote forests	24.2
Populated forests	17.9
Populated rangelands	13.7
Populated rainfed cropland	13.1
Residential rainfed mosaic	11.2
Wild forests	6.9
Populated irrigated cropland	3.5
Remote rangelands	3.3
Residential rangelands	2.2
Remote croplands	1.1
Rainfed mosaic villages	0.9
Residential irrigated cropland	0.8
Pastoral villages	0.6
Dense settlements	0.3
Urban	0.1
Irrigated villages	0.01
Rainfed villages	0.1
Sparse trees	0.1

In addition, figure 4.1.12 shows the sharing of the all anthromes over the Brazilian states involved in the Italian supply in 2018. It stands out that Mato Grosso has the highest portion of remote forests, followed by Pará and Rondônia which are the countries that have the higher portion of wild forests. Moreover, the Populated Rangelands are present mainly in Mato Grosso do Sul and Goiás, while the Residantial Rainfed Mosaic permeates the countries located in Mata Atlantica and in Piauí, along the transition toward the Caatinga. Goias and Mato Grosso do Sul present the highest extension of Rangelands, both Remote and Populated. Rio Grande do Sul figures as the only state to have Populated Irrigated Croplands.

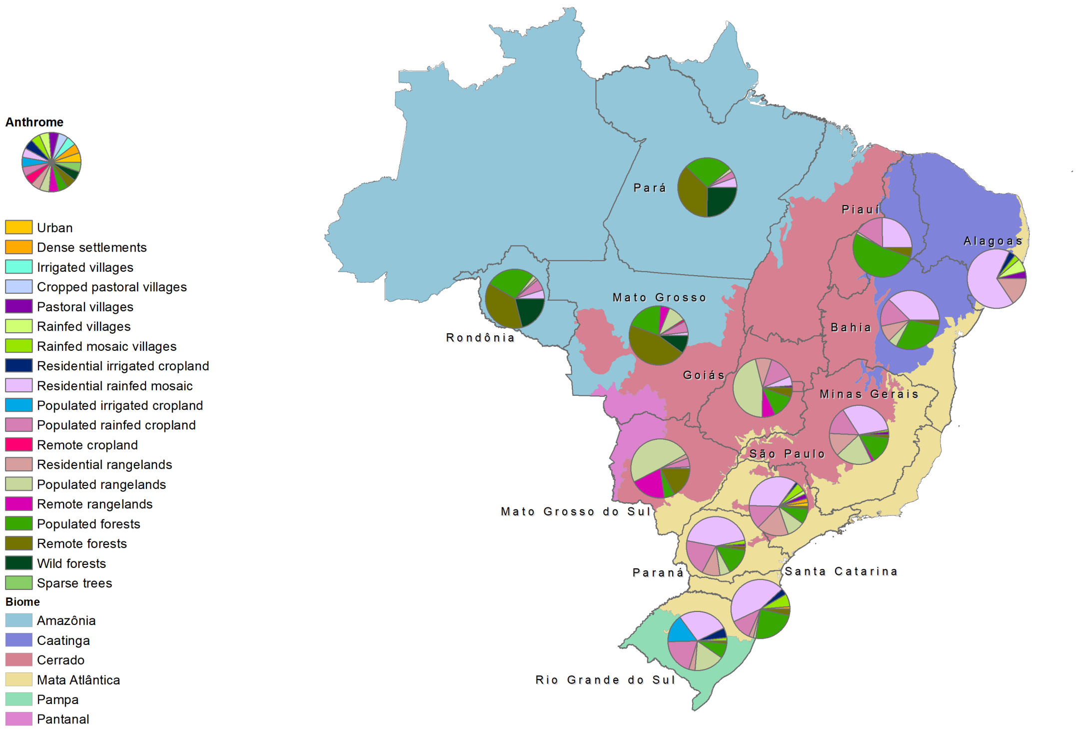

Figure 4.1.12: Anthromes distribution over Brazilian states involved in soybean production toward Italy in 2018 overlapped to the Brazilian natural biomes

Table 4.1.5: Prelevant biomes for each state involved in soybean production toward Italy in 2018

State	**Anthrobiome**	**Cover**
Alagoas	Residential rainfed mosaic	66%
Amazonas	Remote forests	51%
Bahia	Residential rainfed mosaic	37%
Goiás	Populated rangelands	45%
Mato Grosso	Remote forests	45%
Mato Grosso do Sul	Populated rangelands	49%
Minas Gerais	Residential rainfed mosaic	31%
Pará	Remote forests	36%
Paraná	Residential rainfed mosaic	42%
Piauí	Populated forests	51%
Rio de Janeiro	Residential rainfed mosaic	46%
Rio Grande do Norte	Residential rainfed mosaic	56%
Rio Grande do Sul	Residential rainfed mosaic	26%
Rondônia	Remote forests	37%
Santa Catarina	Residential rainfed mosaic	44%
São Paulo	Residential rainfed mosaic	35%

Both from table 4.1.5 and from figure 4.1.4, it is possible to point out that, as it stands from the mapping of Ellis and Ramankutty, the states along the Atlantic Forest of Mata Atlantica are the most anthropized, especially in a mixed composition of residential land use and rainfed croplands, still leaving some space to the Populated Forest. Further, looking at the weighted allocation over states, the average trend highlights that states are characterized by a prelevant anthrome that weights on average the 45% of the total coverage. The only state to differ from this behavior, presenting a higher diversity, is Rio Grande do Sul, where the prelevant antrhome - the Residential Rainfed Mosaic - accounts for the 26%, followed by the Populated Rainfed Cropland (19%), the Populated Rangelands (16%) and the Populated Irrigated Cropland (14%).

The analysis of the anthromes at at the municipality scale has allowed to point out further detailed observations, as shown in figure 4.1.13.

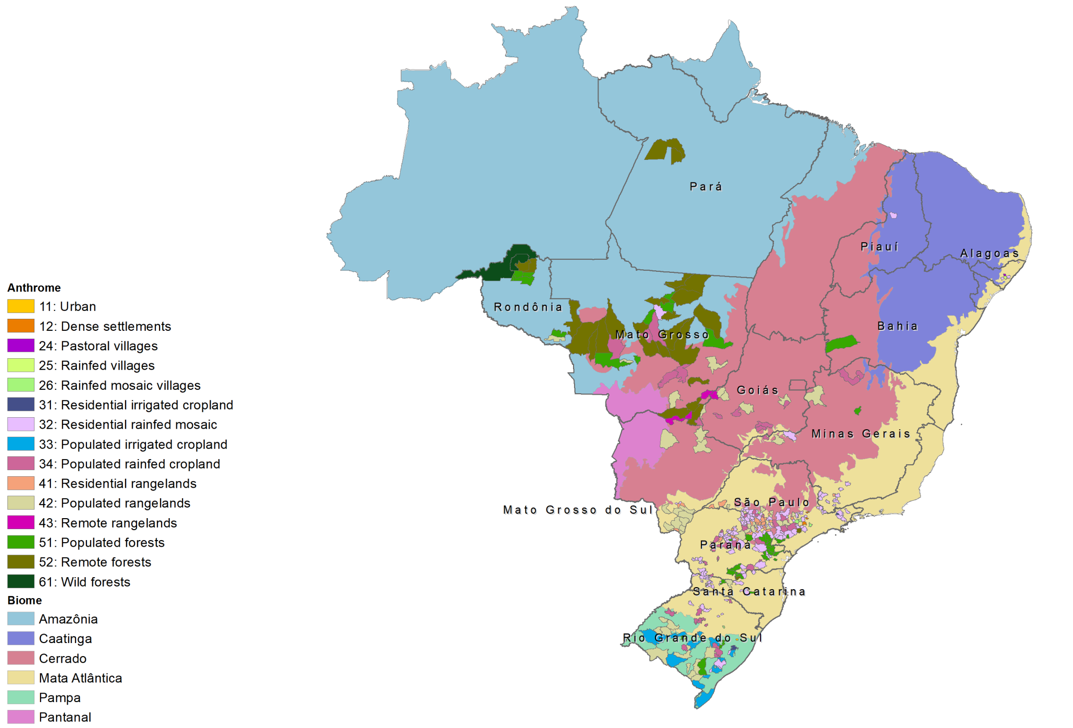

Figure 4.1.13: Prevalent anthromes over Brazilian municipalities involved in soybean production toward Italy in 2018 overlaid to the Brazilian natural biomes

The municipalities in the states of Rondônia, Mato Grosso, Goiás, Minas Gerais, Sao Paulo, Paraná, Santa Catarina and Rio Grande do Sul reflect the anthrome characterization of their states. Differently, the municipalities in Pará, Mato Grosso do Sul, Alagoas, Bahia, being few- or even the only- municipalities of their state involved in the export to Italy, present a specific characterization which may differ from that of their state. From figure 4.1.13 it emerges that, in the state of Bahia, the municipality of Correntina is defined as Populated Forest, the municipalities in the north-western Pará, Santarém and Mojuí dos Campos, belong all to the class of Remote Forest.

What surprise the most in figure 4.1.4 is that the most common anthromes identified for the municipalities of Bahia, Mato Grosso, Rondônia, Piauí and Pará are clearly in contrast with the results obtained for the production at the municipality scale and with the findings illustrated in the subsection 4.1.1, because of both the land use change emerged at the municipality scale and the intensity of production, pointed out by the results in table 4.1.1 and by the graph in figure 4.3.3.

From the results shown in this first section it is possible to infer, in a first step, the characteristics of the Italian supply from Brazil, looking at the results obtained for the municipalities, states, biomes involved and the relatives anthropogenic interactions. It is clear that Mato Grosso and

Rio Grande do Sul are definitely the biggest supplier of Italy. Moreover, the comparison between the results obtained for the Italian import and the ones obtained for the other main European importers, points out Rio Grande do Sul to be a favorite supplier of Italy. Interestingly, important centres of production are also localized in Rondônia, Pará, Goiás and Bahia states, which are located mainly in Amazonia and Cerrado, where the anthromes in 2008 were classified as mainly Remote Forests. This contrast, highlighted from the comparison of the production patters of 2018 and the anthopogenic interactions with biomes, referred to the year 2000 of Ellis and Ramankutty, suggests that in the last 20 years, the soybean cropland conversion played, and is continuing to play, a predominant role in biomes and anthromes alteration and that Italian import supply, investigated at the municipality scale, is not exempted from this scenario. This injection is quite well-known when referring to forest and biodiversity conservation, but what is less stressed is the relation with water resources management and conservation. What it is interesting to underline is the water issue related to the soybean supply and the rising of a scenario where Brazil will be more irrigated, due to both an increasing of the irrigated lands already underway, e.g Correntina in western Bahia and Rio Grande do Sul, and to an intense land use change, e.g central municipalities of Mato Grosso, which may lead to a higher need of irrigation in the crop development stages because of the hydrological alterations consequent to deforestation in a long term prevision.

4.2 Virtual water trade at the municipality scale

The next section reports and discusses the water footprint assessment of the Italian soybean import at the sub-national scale of production. Firstly, it is presented the unitary water footprint obtained at the municipality scale, which provides a water-efficiency evaluation of production, that depends on the municipality's geographical and agricultural patterns. Then, the section illustrates and defines the identified water footprint volumes, flowing from each municipality to Italy in 2018. The achieved water footprint results are further contextualized with the findings of the previous section 4.1 on biomes and anthropogenic influence.

4.2.1 Unitary water footprint at the municipality scale

The results obtained by merging the crop unitary water footprint data at 5 arc minutes spatial resolution (Tuninetti et al., 2015) with Trase production data of 2018, as described in 3, are hereafter illustrated.

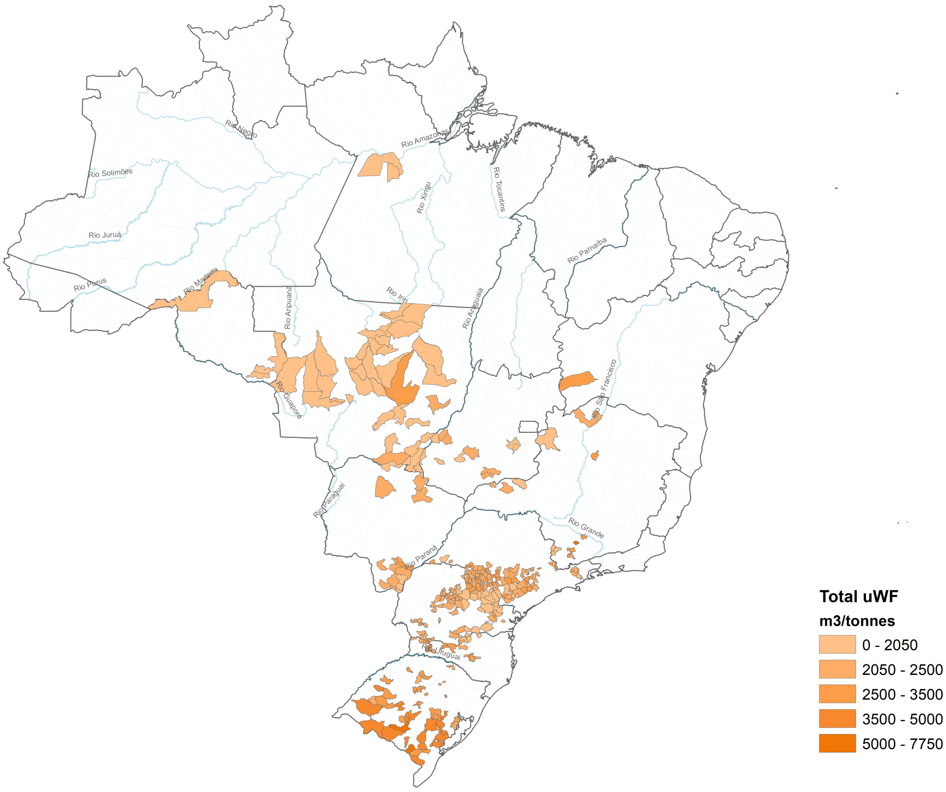

Figure 4.2.1: Total unitary water footprint of Italian soybean import in 2018 at the municipality scale

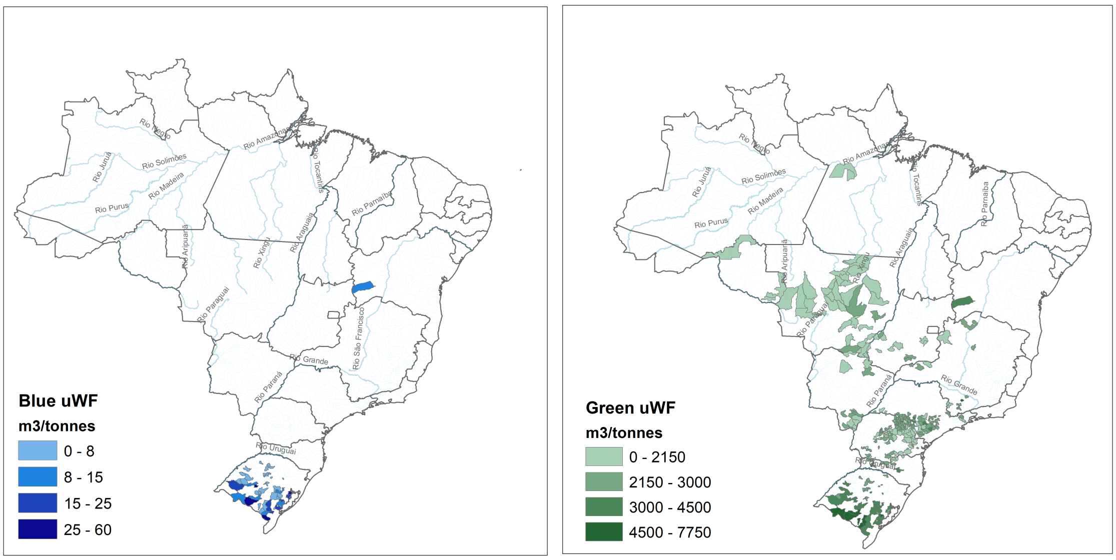

Figure 4.2.2: Blue and green unitary water footprint of Italian soybean import in 2018 at the municipality scale

The map in figure 4.2.1 immediately points out that: the highest values of unitary water footprint, uWF, figure in the southern region, in the state of Rio Grande do Sul, followed by the states of

Santa Catarina and Paraná in the same region; but high-medium values are also characteristic of the municipality of Correntina, in western Bahia - in the central-east region - and in some central municipalities of Mato Grosso. Figure 4.2.2 compares the blue and green contributions providing a clear outcome. Blue water is almost totally sourced in Rio Grande do Sul, which present also the peak values -from 25 up to 60 $m^3/tonnes$-, though a clear exception is provided by the municipality of Correntina, which features in the medium range from 5 to 8 $m^3/tonnes$. The green unitary water footprint provides the biggest contribution to the total uWF, interestingly, the southest municipalities of Rio Grande do Sul and Correntina, show a medium -high green uWF along with the maximum values of the blue uWF. Results tell also that highest blue uWF are located in the municipalities of Jaguarão ($5.67e+01m^3/tonnes$), Dom Pedrito ($3.57e+01m^3/tonnes$) and Dilermando de Aguiar ($2.70e+01m^3/tonnes$). Correntina figures with ($1.02e+01m^3/tonnes$) of blue uWF, as the only municipality accounting for blue water outside Rio Grande do Sul. Generally, green and blue uWF differ of an order of magnitude of 1000 $m^3/tonnes$.

Table 4.2.1: Major unitary water footprints at the municipality scale

State (-)	**Municipality** (-)	**Total uWF** (m^3/ton)	**Blue uWF** (m^3/ton)	**Green uWF** (m^3/ton)	**Production** ($tonnes$)
Rio Grande do Sul	Pinheiro Machado	7.75E+03	3.97E+00	7.75E+03	5.54E+01
Rio Grande do Sul	Pedras Altas	7.54E+03	5.71E+00	7.54E+03	2.65E+02
Minas Gerais	Varginha	6.45E+03	0.00E+00	6.45E+03	1.46E+00
Rio Grande do Sul	Lavras do Sul	6.25E+03	1.18E+01	6.24E+03	4.06E+02
Santa Catarina	Nova Erechim	4.86E+03	0.00E+00	4.86E+03	1.38E+01
Santa Catarina	Nova Itaberaba	4.82E+03	0.00E+00	4.82E+03	8.70E+00
Rio Grande do Sul	Sant'Ana do Livramento	4.73E+03	1.02E+01	4.72E+03	3.29E+03
Rio Grande do Sul	Hulha Negra	4.70E+03	6.47E+00	4.69E+03	1.82E+02
Santa Catarina	Cordilheira Alta	4.67E+03	0.00E+00	4.67E+03	3.34E+00
Rio Grande do Sul	Cristal	4.58E+03	2.02E+01	4.56E+03	1.11E+02
Rio Grande do Sul	Dom Pedrito	4.57E+03	3.57E+01	4.55E+03	1.51E+03
Rio Grande do Sul	Encantado	4.40E+03	1.00E-02	4.40E+03	3.04E+02
Santa Catarina	União do Oeste	4.36E+03	0.00E+00	4.36E+03	8.05E+00
Rio Grande do Sul	São Lourenço do Sul	4.29E+03	1.41E+01	4.28E+03	2.84E+02
Rio Grande do Sul	Encruzilhada do Sul	4.25E+03	1.03E+00	4.25E+03	4.77E+02
Santa Catarina	Coronel Freitas	4.05E+03	0.00E+00	4.05E+03	3.19E+01
Rio Grande do Sul	Piratini	3.89E+03	1.69E+01	3.89E+03	5.54E+02
Rio Grande do Sul	Pelotas	3.79E+03	1.72E+01	3.78E+03	3.03E+02
Rio Grande do Sul	Itacurubi	3.77E+03	2.22E+00	3.76E+03	4.42E+02
Santa Catarina	Santiago do Sul	3.74E+03	0.00E+00	3.74E+03	1.66E+01
Santa Catarina	Quilombo	3.73E+03	0.00E+00	3.73E+03	7.66E+01
Rio Grande do Sul	Butiá	3.67E+03	1.02E+01	3.67E+03	2.30E+02
Rio Grande do Sul	São Pedro do Sul	3.66E+03	1.26E+01	3.65E+03	3.15E+02
Rio Grande do Sul	Dom Feliciano	3.66E+03	4.07E-01	3.66E+03	1.04E+01
Rio Grande do Sul	Morro Redondo	3.65E+03	9.13E-01	3.65E+03	2.13E+01
Rio Grande do Sul	Alegrete	3.64E+03	1.57E+01	3.63E+03	6.62E+02
Rio Grande do Sul	Jaguarão	3.53E+03	5.67E+01	3.48E+03	2.75E+03
Rio Grande do Sul	Vila Nova do Sul	3.52E+03	3.78E-01	3.52E+03	1.70E+02
Rio Grande do Sul	São Sepé	3.51E+03	7.72E+00	3.51E+03	8.92E+02
Rio Grande do Sul	Dilermando de Aguiar	3.50E+03	2.70E+01	3.48E+03	5.20E+02

Values in 4.2.1 shows the major thirty total uWF resulted at the municipality scale. It can been seen that Varginha in Minas Geráis, is the first municipality not located in the southern region -but in the southern-east one- to have the highest total uWF, accounting for only green water. Also, though the municipalities in Rio Grande do Sul account for both blue and green water, some municipalities of Santa Catarina, São Paulo ad Paraná overcome its values.

4.2.2 Water footprint volumes at the municipality scale

The analysis turns now to the volumes obtained at the municipality scale.

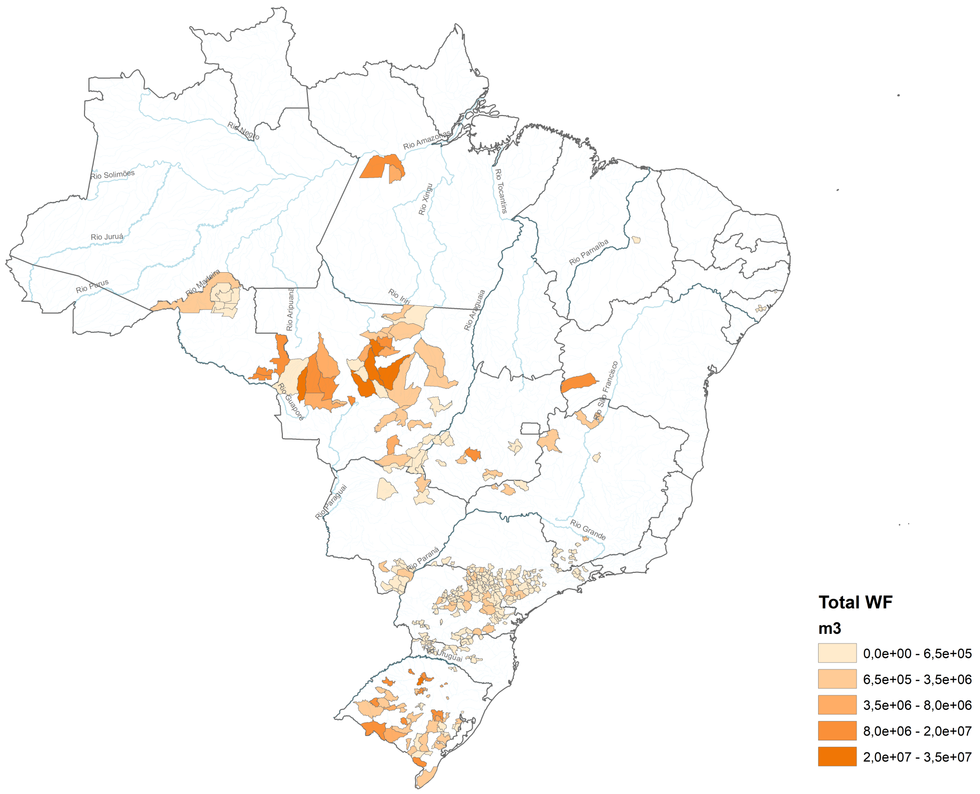

Figure 4.2.3: Total water footprint volumes of Italian soybean import in 2018 at the municipality scale

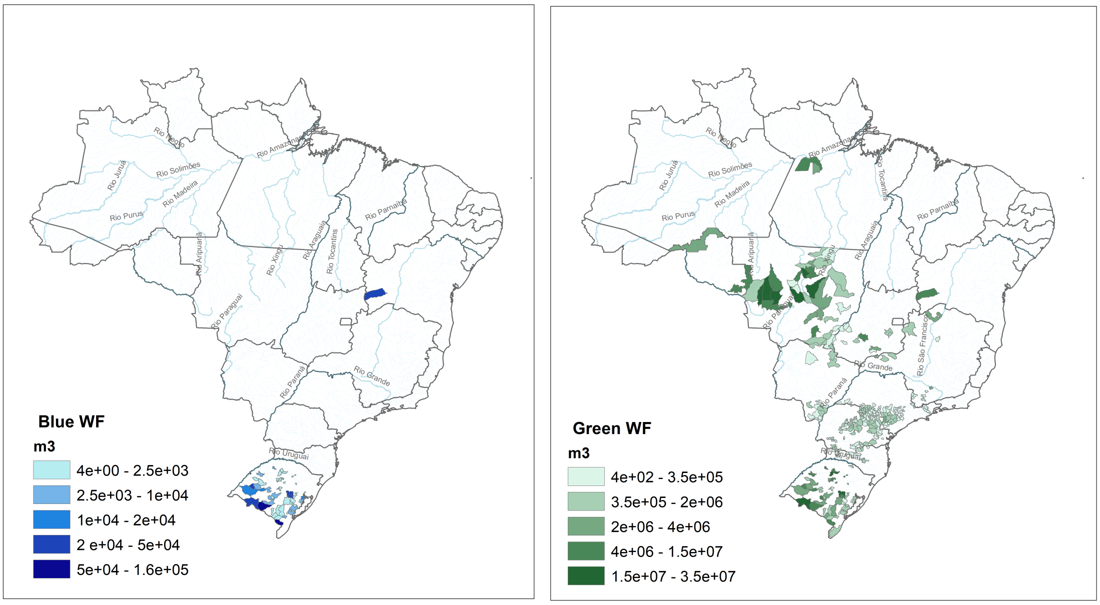

Figure 4.2.4: Blue and green water footprint volumes of Italian soybean import in 2018 at the municipality scale

The comparison between 4.2.4 and 4.2.2 stresses the influence exerted on water footprint volumes by the yearly production over each the municipality involved. Indeed, while the blue uWF and the blue WF are distributed over the involved municipality similarly, the green WF volumes extend over the municipalities differently from the green uWF. The largest WF volumes are located in Mato Grosso municipalities, as well as in Rondônia and Pará. The uWF peaks of Rio Grande do Sul and Correntina -in Bahia state- of the uWF are though smoothed by the rising of the values of productions per year in the municipalities of the central and northern regions.

Table 4.2.2: Major virtual water flows toward Italy in 2018 at the municipality scale

State (-)	**Municipality** (-)	**Total WF** (m^3)	**Blue WF** (m^3)	**Green WF** (m^3)	**Production** (tonnes)
Mato Grosso	Sorriso	3.52E+07	0.00E+00	3.52E+07	2.08E+04
Mato Grosso	Campos de Júlio	3.11E+07	0.00E+00	3.11E+07	1.68E+04
Mato Grosso	Nova Ubiratã	2.67E+07	0.00E+00	2.67E+07	1.52E+04
Rio Grande do Sul	Santa Bárbara do Sul	2.61E+07	7.65E+02	2.61E+07	1.14E+04
Mato Grosso	Sinop	2.35E+07	0.00E+00	2.35E+07	1.51E+04
Mato Grosso	Nova Mutum	2.07E+07	0.00E+00	2.07E+07	1.13E+04
Mato Grosso	Sapezal	1.97E+07	0.00E+00	1.97E+07	1.04E+04
Rio Grande do Sul	Rio Pardo	1.72E+07	4.14E+04	1.72E+07	5.72E+03
Mato Grosso	Campo Novo do Parecis	1.61E+07	0.00E+00	1.61E+07	8.50E+03
Rio Grande do Sul	Sant'Ana do Livramento	1.56E+07	3.54E+04	1.56E+07	3.29E+03
Rio Grande do Sul	Carazinho	1.56E+07	3.32E+02	1.56E+07	6.21E+03
Rio Grande do Sul	Fortaleza dos Valos	1.48E+07	4.28E+02	1.48E+07	5.84E+03
Rio Grande do Sul	Santo Augusto	1.46E+07	4.27E+03	1.46E+07	5.15E+03
Rio Grande do Sul	Chapada	1.39E+07	3.98E+02	1.39E+07	5.53E+03
Rondônia	Cerejeiras	1.39E+07	1.45E+02	1.39E+07	7.89E+03
Mato Grosso	Cláudia	1.30E+07	0.00E+00	1.30E+07	7.92E+03
Rio Grande do Sul	Santa Margarida do Sul	1.27E+07	3.58E+03	1.27E+07	3.81E+03
Rio Grande do Sul	São Luiz Gonzaga	1.21E+07	3.00E+03	1.21E+07	3.72E+03
Bahia	Correntina	1.15E+07	3.97E+04	1.15E+07	3.86E+03
Rondônia	Corumbiara	1.14E+07	3.38E+02	1.14E+07	6.60E+03
Goiás	Paraúna	1.05E+07	0.00E+00	1.05E+07	5.07E+03
Rondônia	Vilhena	1.04E+07	1.90E+02	1.04E+07	6.32E+03
Rio Grande do Sul	Manoel Viana	1.02E+07	2.18E+04	1.02E+07	4.55E+03
Mato Grosso	Nortelândia	1.01E+07	0.00E+00	1.01E+07	5.13E+03
Pará	Santarém	9.96E+06	0.00E+00	9.96E+06	5.72E+03
Rio Grande do Sul	Jaguarão	9.75E+06	1.56E+05	9.60E+06	2.75E+03
Mato Grosso	Santa Carmem	7.78E+06	0.00E+00	7.78E+06	4.89E+03
Rio Grande do Sul	Dom Pedrito	7.01E+06	5.41E+04	6.96E+06	1.51E+03
Rio Grande do Sul	Camargo	6.66E+06	0.00E+00	6.66E+06	3.06E+03
Mato Grosso	Rondonópolis	5.48E+06	0.00E+00	5.48E+06	2.79E+03

Results in table **??** show that the largest flow of virtual water from a Brazilian municipality -3.52e+07 m^3 (3% of the total export flow)- comes from Sorriso in the State of Mato Grosso. This volume, which is totally contributed by green water, supplies the highest Italian import from a Brazilian municipality, see table 4.1.1. Relating these outcomes with table 4.1.1 reporting the major producer municipalities, it is possible to notice that, as expected by the results in figure 4.2.1, municipalities in the states of the central and northern regions as Mato Grosso, Rondônia and Pará, present a lower volume of water footprint with respect to the amount of production provided per year. The first municipality among the first five major water footprint volumes to account also for blue water is Santa Bárbara do Sul, in Rio Grande do Sul, with total $2.61e+07m^3$, of which $7.65e+02m^3$ are blue, and a production in 2018 of $1.14e+04$ tonnes . The first thirty water footprint volumes account for the 70% of the total flow leaving from the 374 municipality analyzed to Italy.

Map in figure shows **??** the highest flow of blue water -1.56 $e+05m^3$- comes from Jaguarão, in the State of Rio Grande do Sul, which figures as well in table 4.1.1 as the thirtieth Italian soybean supplier per year, the eleventh of Rio Grande do Sul, and as the greater blue water demanding municipality per tonnes of production in table. One of the most interesting findings from this map is the case of Correntina. Results show that this municipality accounts for 1.15e+07 total m^3, of which 3.97 e+04 m^3 of blue water, providing 3856 *tonnes* along 2018. As pointed out in the previous section of this chapter, 4.1, Bahia state has faced an increment of the 61% of the irrigated area (ha) in 8 years, from 2006 to 2014 being the western side rich of water bodies - including three water basins, tributaries of Rio São Francisco. Here the anthropic injection in the latest years changed the local ecosystemic features and since at least 2010 water conflicts are arising (Pousa et al., 2019). In this context, Correntina, was protagonist in 2017 of a resonating protest in the Brazilian national scene, against the appropriation of water by agribusiness in the area, after that a farm had received new installations and equipment for irrigation (Pousa et al., 2019).

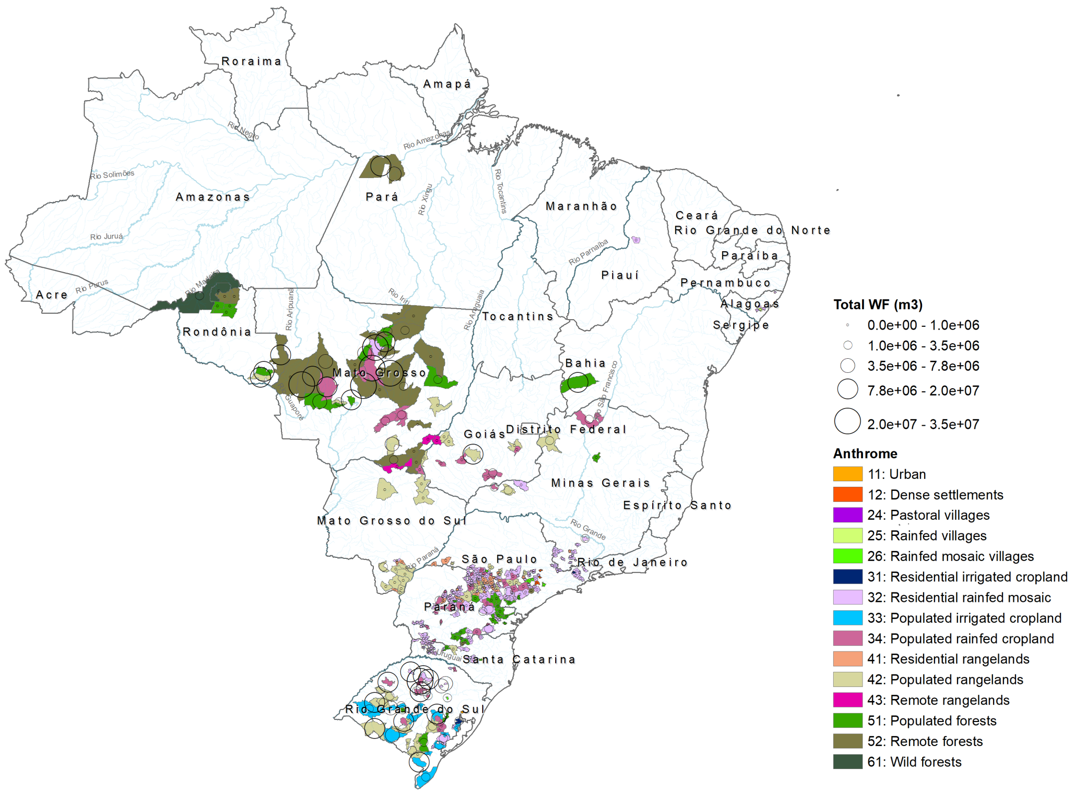

Figure 4.2.5: Brazilian municipalities involved in soybean production toward Italy in 2018: water footprint volumes overlapped to the anthropogenic biomes of year 2000 at the municipality scale. Bubbles' size represent the water footprint volumes of each municipality, the color scheme indicates the anthropogenic biome at the municipality scale

Figure 4.2.5 combines the results of the section 4.1 and the water footprint volumes obtained for the year 2018 of the analyzed municipalities, stressing what has been highlighted regarding the land use change at the municipality scale and its implications with water use. Table 4.2.3 reports the first thirty water footprint volumes correlated with the respective anthromes.

Table 4.2.3: Major water footprint volumes and anthromes by Ellis and Ramankutty

Municipality (-)	**Anthrome** (-)	**State** (-)	**Total WF** (m^3)
Sorriso	Populated rainfed cropland	Mato Grosso	3.52E+07
Campos de Júlio	Remote forests	Mato Grosso	3.11E+07
Nova Ubiratã	Remote forests	Mato Grosso	2.67E+07
Santa Bárbara do Sul	Populated rainfed cropland	Rio Grande do Sul	2.61E+07
Sinop	Residential rainfed mosaic	Mato Grosso	2.35E+07
Nova Mutum	Remote forests	Mato Grosso	2.07E+07
Sapezal	Remote forests	Mato Grosso	1.97E+07
Rio Pardo	Populated irrigated cropland	Rio Grande do Sul	1.72E+07
Campo Novo do Parecis	Populated rainfed cropland	Mato Grosso	1.61E+07
Sant'Ana do Livramento	Populated rangelands	Rio Grande do Sul	1.56E+07
Carazinho	Residential rainfed mosaic	Rio Grande do Sul	1.56E+07
Fortaleza dos Valos	Populated rainfed cropland	Rio Grande do Sul	1.48E+07
Santo Augusto	Residential rainfed mosaic	Rio Grande do Sul	1.46E+07
Chapada	Residential rainfed mosaic	Rio Grande do Sul	1.39E+07
Cerejeiras	Populated rangelands	Rondônia	1.39E+07
Cláudia	Populated forests	Mato Grosso	1.30E+07
Santa Margarida do Sul	Populated rainfed cropland	Rio Grande do Sul	1.27E+07
São Luiz Gonzaga	Populated rainfed cropland	Rio Grande do Sul	1.21E+07
Correntina	Populated forests	Bahia	1.15E+07
Corumbiara	Populated forests	Rondônia	1.14E+07
Paraúna	Populated rangelands	Goiás	1.05E+07
Vilhena	Remote forests	Rondônia	1.04E+07
Manoel Viana	Populated rangelands	Rio Grande do Sul	1.02E+07
Nortelândia	Populated forests	Mato Grosso	1.01E+07
Santarém	Remote forests	Pará	9.96E+06
Jaguarão	Populated irrigated cropland	Rio Grande do Sul	9.75E+06
Santa Carmem	Remote forests	Mato Grosso	7.78E+06
Dom Pedrito	Populated irrigated cropland	Rio Grande do Sul	7.01E+06
Camargo	Residential rainfed mosaic	Rio Grande do Sul	6.66E+06
Rondonópolis	Populated rangelands	Mato Grosso	5.48E+06

The findings of this chapter suggest that where the highest- or the most unexpected- volumes of water footprint emerge, it should be expected a trend of anthromes turning from Wild, Remote and Populated Forests toward intense Rainfed Croplands and Irrigated Croplands. In analogy with an ecological succession, defined as the set of changes occurring in the structure of a community over time, (Smith and Smith, 2006). Figure 4.2.6 models the anthromes ecosystemic succession from wild to more harvested systems, over time and over agricultural expansion, expected in the light of the water footprint volumes resulted at the municipality scale for the productions of 2018.

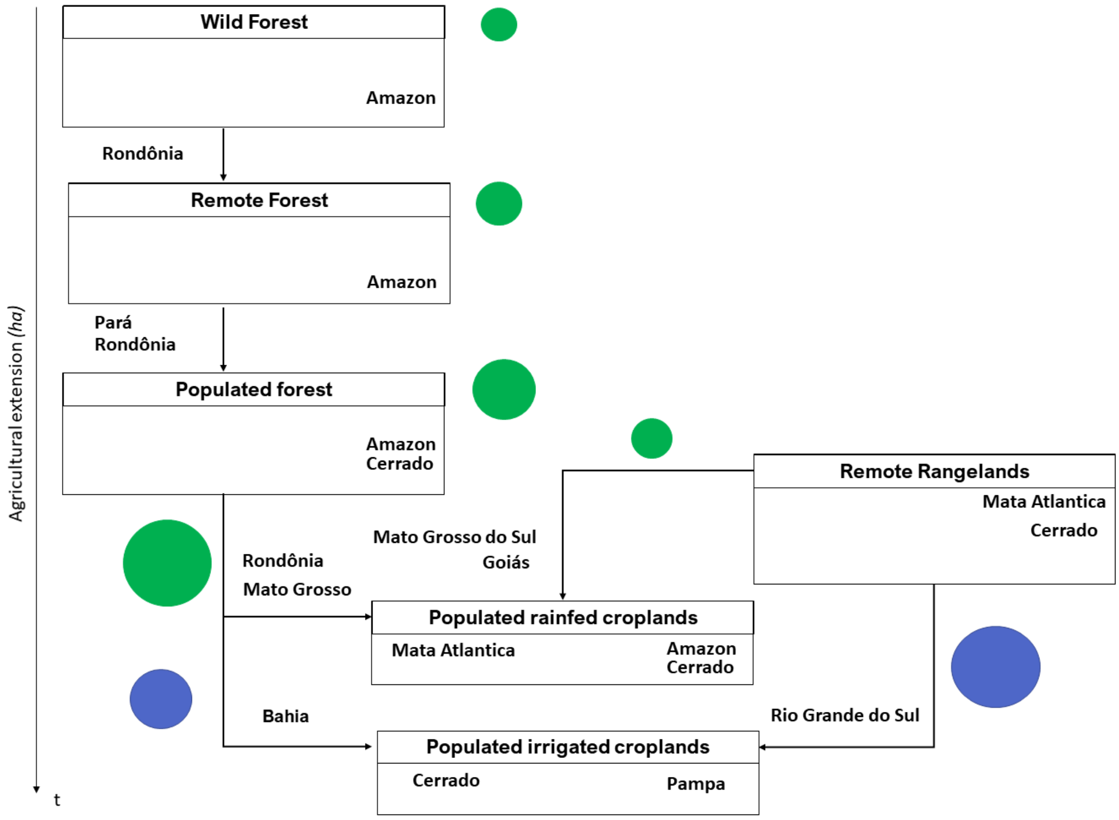

Figure 4.2.6: Anthromes regression likely expected in the light of the water footprint volumes observed at the municipality scale in contrast with the anthromes mapped by Ellis and Ramankutty (2008) reffering to the year 2000

The regression from a less human-contaminated anthrome to one more anthropized brings along a changing of the volume and type of the water footprint. Firstly, the changing in land use is driven by a conversion into croplands, thus the precipitation will contribute to the crop growing, thus the green WF grows in the regression from Wild Forest to Populated Rainfed Croplands. The agricultural irrigated activity detected in western Bahia, suggests that a Populated Forest has converted into a Populated irrigated cropland, giving born to a new blue WF volume. In Rio Grande do Sul, the blue water use increased as well in the areas already irrigated, but also in the Remote Rangelands, which are classified as not suitable for agriculture, thanks to irrigation, technologies and chemicals, have been converted into cropland. The Remote Rangelands converting into Populated rainfed croplands, are expected as well to have been boost by chemicals and techonologies.

4.3 The virtual water trade at the company's scale

The next section of results reports the outcomes of the water footprint assessment associated to the exporter companies trading soybean to Italy to Italy in 2018.

At the global scale, between 2010 and 2015, five companies dominated 90% of soybeans exports produced in Brazil and allocated worldwide: Amaggi, Adm, Bunge, Cargill and Louis Dreyfus.

Results for Italy, obtained through the methodology exposed in chapter 3 reveal that in 2018 Italy imported from 38 companies, over 297 companies counted as exporter groups of soybean from Brazil in 2018. Also, what surprises is that the largest supplier is the Bianchini company, instead of being one of the five national dominant companies reported in table **??**. Though, in 2016 Bianchini was the sixth trader company of soybean from Brazil globally, even if detaching itself from the volumes traded by the biggest five. The output obtained, from Trase database elaboration shows that Italy has traded in 2018 with 38 companies, but just 19 of them have sources from traced municipalities. These 29 companies accounts for $3.03e + 05$ *tonnes*, produced throughout the 374 municipalities analyzed in the previous sections. Table 4.3.1 itemizes the 38 trading companies, while table 4.3.2, the tonnes traded by the companies of which the sourcing municipalities are detected by Trase.

Table 4.3.1: Exporter companies trading with Italy in 2018

Exporter company
Adm
Aesa Automolas Equipamentos Ltda.
Agro Latina
Agrocontato Comercio E Representacoes De Produtos Agropecuarios Ltda
Agropecuaria 3 Poderes - Comercio, Exportacao E Importacao Ltda
Amaggi
Augustinho Comercio Exportacao E Importacao Ltda
Baldo
Bianchini
Bremil Industria De Produtos Alimenticios
Bunge
C M F Padovese Calcados Eireli
Cargill
Casale Equipamentos
Citroleo Industria E Comercio De Oleos Essenciais Ltda
Cofco
Cooperativa Dos Agricultores Da Regiao De Orlandia
Crista Industria E Comercio
Delga Industria E Comercio S/A
Dti Sementes S.A.
Etgran Mineracao Importacao E Exportacao De Produtos
Euroalimentos
Gavilon
Louis Dreyfus
Masipack Industria E Comercio De Maquinas Automaticas
Miriri Alimentos E Bioenergia
Monte Negro Granitos
Ms Pescados Comercio, Importacao E Exportacao
Poquema Industria E Comercio De Moveis Ltda
Sabara Quimicos E Ingredientes
Savixx Comercio Internacional
Selecta
Sinagro Produtos Agropecuarios
Terra Santa Agro
Uby Agroquimica S.A
Ungi Cafe Comercio, Industria E Exportacao Ltda - Epp

Table 4.3.2: Exporter companies trading with Italy in 2018 from traced municipalities

Exporter company (-)	**Trade** (*tonnes*)
Bianchini	6.70E+04
Cofco	6.24E+04
Cargill	4.41E+04
Bunge	3.87E+04
Amaggi	3.11E+04
Louis Dreyfus	2.20E+04
Gavilon	9.28E+03
Adm	8.27E+03
Baldo	5.67E+03
Terra Santa Agro	3.86E+03
Ms Pescados Comercio, Importacao E Exportacao	2.23E+03
Agrocontato Comercio E Representacoes De Produtos Agropecuarios Ltda	1.81E+03
Sinagro Produtos Agropecuarios	1.65E+03
Augustinho Comercio Exportacao E Importacao Ltda	1.16E+03
Dti Sementes S.A.	1.01E+03
Ungi Cafe Comercio, Industria E Exportacao Ltda - Epp	8.06E+02
VOTORANTIM METAIS ZINCO S.A.	6.82E+02
Savixx Comercio Internacional	4.38E+02
Selecta	3.25E+02

Bianchini, Cofco, Cargill, Bunge, Amaggi and Louis Dreyfus account for the 88% of the traced supply. Interestingly, from table 4.3.2 it emerges that Adm, one of the dominant trader worldwide of soybean from Brazil, is just eight in the Italian supply, after two smaller companies such as Bianchini and Gavilon.

4.3.1 Unitary water footprint at the company's scale

Hereafter in figure 4.3.1 is reported the map obtained pivoting the unitary water footprint values at the municipality scale on the major six exporter companies analyzed.

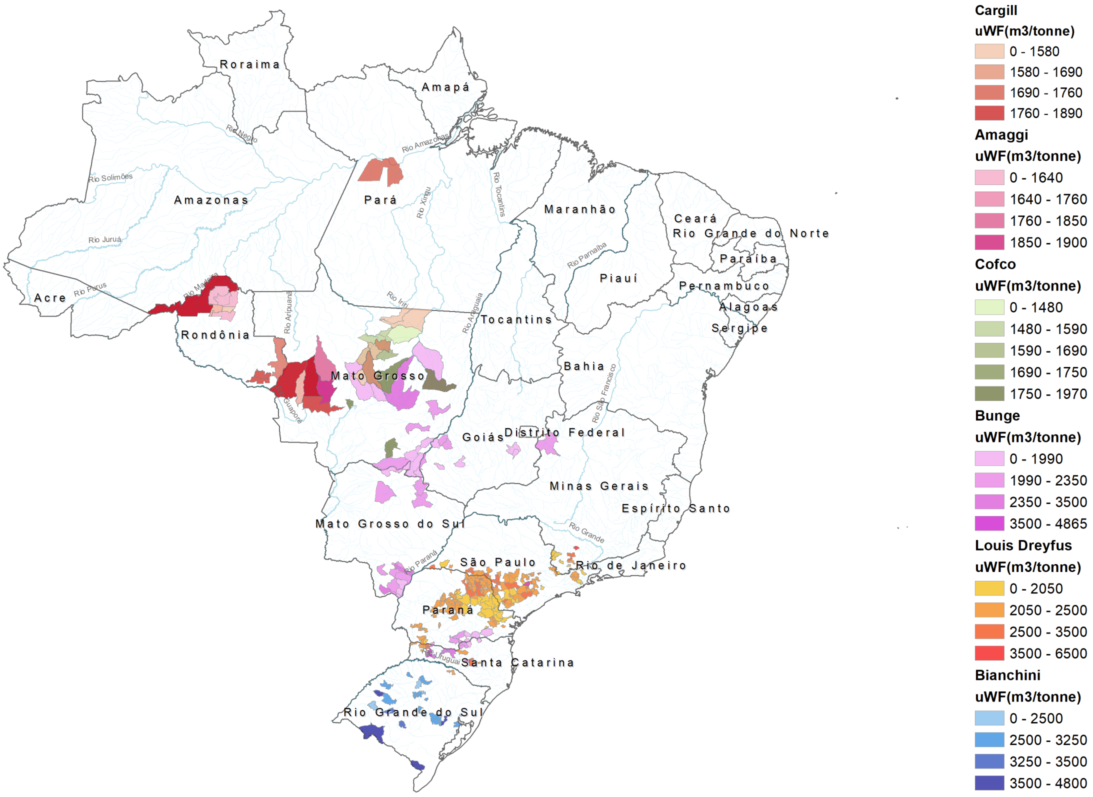

Figure 4.3.1: Unitary water footprints related to the production of the analyzed companies. Each company is represented by a color, whose gradient shows the unit water footprint of soybean production at the municipality scale

Immediately, the map in figure 4.3.1 shows how companies are distributed over the municipalities traced and the gradient of their water-efficiencies. It emerges that Cargill is the company extending the most in the north, followed by Amaggi and Cofco. These three share the area of Mato Grosso, where they operate sometimes in the same municipality and where production, as shown in section 4.1 is the most intense of the country, their ranges of water-efficiency are quite similar. Bunge is the company which extends its production over the longest stretch of latitude, its unitary water footprint ranges start to stray from that of Cargill, Amaggi and Cofco. Luois Dreyfus manages the export from the many, small and dense municipalities of Sao Paulo, Parana and Santa Catarina; Bianchini holds the trade from the state of Rio Grande do Sul. For these two companies, water-requirements per tonne of production starts growing: their low-medium range of cubic meters per tonne corresponds to the high range values of Cargill, Amaggi and Cofco.

Boxplots in figure 4.3.2 clearly illustrate how the companies share different water-efficiencies over their supplies. The extremes of the box represent the percentiles corresponding to the first and third quantiles (25% and 75%), the line which splits the box is the median, the circle is the weighted average. The bottom of the inferior whisker represents the percentile corresponding to the 10% while the top of the upper whisker the percentile related to the 90% of the total production. The distance between the first and third quantiles, along with the length of the whiskers, point out the grade of dispersion and of skewness of the percentiles distribution characteristics of each company. The most symmetric curve are the ones of Cofco and Louis Dreyfus, while the one with the highest skewness is that of Bunge, where the median is strongly pointed toward the third quantile while percentiles from the 25% to the 10% are dispersed along an extended tail.

Amaggi, Cofco and Bunge are heavily skewed toward the ninethiet-percentile, while Bianchini tends to skew toward the tenth-percentile uWF. This observation manifests that Amaggi, Cofco and Bunge present outliers at the bottom of their distribution, respectively: 1643 $m^3/tonnes$, 1580 $m^3/tonnes$ and 1853 $m^3/tonnes$; while Bianchini's outlier ninethiet-percentile uWF: 2696 $m^3/tonnes$.

Cargill and Amaggi present the shortest fields of variation, while Bianchini emerges as the company with the hugest range, from $m^3/tonnes$ up to $m^3/tonnes$.

The weighted averages, itemized also in table 4.3.3, tend generally to distance themselves from the median: only for Amaggi these two almost combine. Even, in the case of Bunge and Louis Dreyfus the medium values collocate themselves between the twenthy-fifth and the tenth - percentiles uWF.

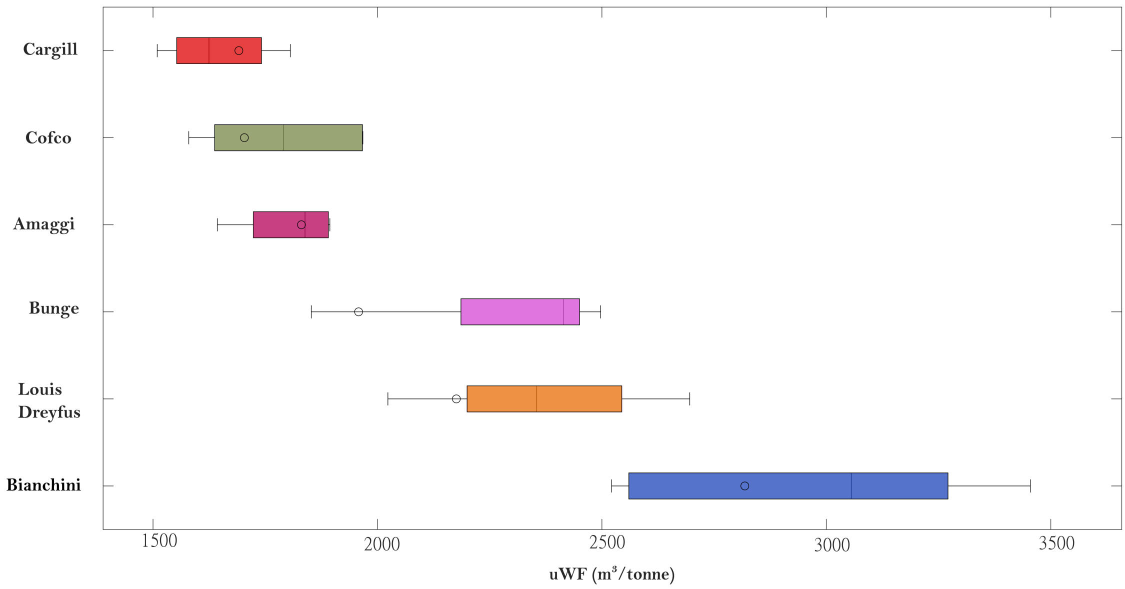

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Figure 4.3.2: Comparative boxplots of soybean uWF related to the production of the analyzed companies. The bottom and top of the whiskers represent the percentile(10%) and the percentile(90%); the extremes of the box represent the percentile(25%) and the percentile (75%); the line splitting the box is the median and the circle is the averaged medium value

Table 4.3.3: Weighted averages of the unitary water footprint of the analyzed companies

Company (-)	**uWF weighted average** ($m^3/tonnes$)
Cargill	1691
Cofco	1704
Amaggi	1831
Bunge	1958
Louis Dreyfus	2176
Bianchini	2818

Table 4.3.4: Comparison between the uWF percentiles relative to the 10%, 25%, 50%, 75%, 90% of production for the analyzed companies

Company (-)	**uWF(10%)** ($m^3/tonnes$)	**uWF (25%)** ($m^3/tonnes$)	**uWF(50%)** ($m^3/tonnes$)	**uWF (75%)** ($m^3/tonnes$)	**uWF(90%)** ($m^3/tonnes$)
Cargill	1509	1567	1625	1720	1806
Cofco	1580	1656	1790	1966	1968
Amaggi	1643	1750	1839	1890	1894
Bunge	1853	2297	2415	2435	2497
Louis Dreyfus	2023	2258	2354	2494	2696
Bianchini	2522	2573	3056	3210	3455

Both the comparative boxplots in figure 4.3.2 and the weighted average values of table 4.3.3, if compared with the map in figure 4.3.1 interestingly outline a correlation between the increasing of the southern latitude and the increasing of water-requirment per tonne of production. Though, the geography of production is been investigated: the weighted centroids of production per each company are represented in the following map in figure 4.3.3, where these are overlapped to the map of biomes in figure 4.1.6.

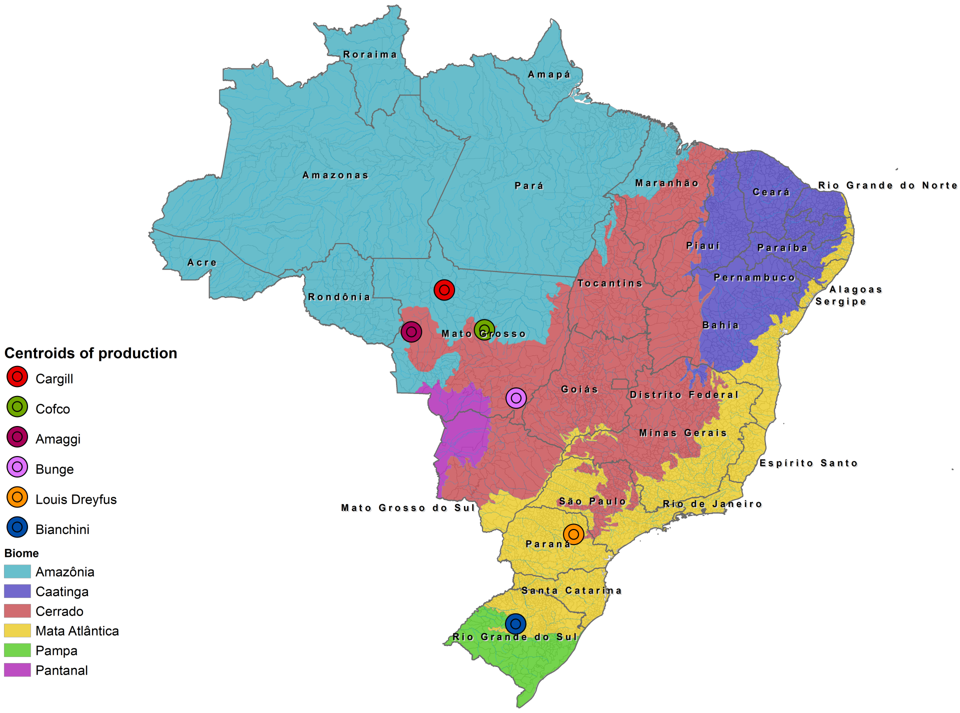


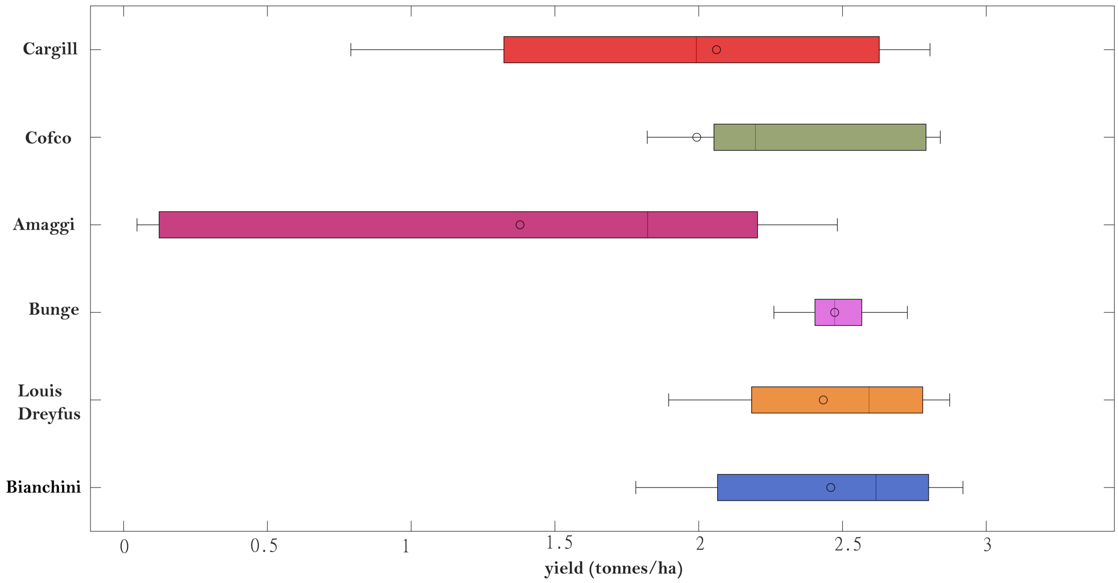
Figure 4.3.3: Weighted centroids of production of the analyzed companies overlaid to the Brazilian biomes

Table 4.3.5: Weighted averaged latitudes of production of the analyzed companies

Company	Latitude
Cargill	10° 33' 5' S
Cofco	12° 45' 42' S
Amaggi	12° 52' 15' S
Bunge	16° 32' 60' S
Louis Dreyfus	24° 6' 60' S
Bianchini	29° 5' 37' S

The next step investigates the soybean yields mapped in Monfreda et al. (2008), for each exporting company, in order to detect whether the increasing of uWF is due to low yields ($tonnes/ha$) or to high rates of evapotranspiration (mm/day). The trend observed for yields, is significantly different from that of the uWF: values appear to be more uniform among trading companies, with respect to the uWF. In particular, Bunge, Louis Dreyfus and Bianchini, operating at the central-southern latitudes show similar values of weighted average, while the range of variation from the percentile corresponding to 25% quantile and that corresponding to the 75% quantile increases with latitude. Moreover, Louis Dreyfus and Bianchini share the same length and symmetry of the whiskers. Amaggi and Cargill stand out for the high variation of the range, also, Amaggi presents the lowest mean value: 1.8 $tonnes/ha$. The highest average yields are those of Bunge, 2.47 $tonnes/ha$ and

Bianchini, 2.46 *tonnes/ha*. Bunge emerges also as the company where yields have the slighest dispersion around the median and the mean, that, in this case, match. Amaggi and Cofco come up as the ones with the lowest medium values, though the median is skewed toward the percentile corresponding to 75% quintile.



;

Figure 4.3.4: Comparative boxplots of soybean yields related to the production of the analyzed companies. The bottom and top of the whiskers represent the percentile(10%) and the percentile(90%); the extremes of the box represent the percentile(25%) and the percentile (75%); the line splitting the box is the median and the circle is the averaged medium value

Table 4.3.6: Weighted averaged soybean yields at the company's scale

Company (-)	**yield weighted average** (*tonnes/ha*)
Cargill	2.06
Cofco	1.99
Amaggi	1.38
Bunge	2.47
Louis Dreyfus	2.43
Bianchini	2.46

These results outline that South-Central-East and South regions are characterized by better yields, where croplands were present since at least before years 2000, as illustrated in figure 4.1.11. Though, the areas held by Cargill, Cofco, Amaggi experienced an expansion of agriculture and an increasing of productivity, with a consequent improvement of yields. According to FAOSTAT, in 2000 the national yield for soybean in Brazil was equal to 2.4 *tonnes/ha*, value that almost corresponds to that of Bunge, Louis Dreyfus and Bianchini. In 2018 FAOSTAT reports a national yield of 3.4 *tonnes/ha*, showing an increase by 30% since year 2000. Thus, in 2018 it is expected an overall increase of yields and that Cargill, Cofco and Amaggi may behave more homogeneously with the distributions of Bunge, Louis Dreyfus and Bianchini. Thus, results show it is the latitude to determine the higher crop water-requirements and thus, generating higher evapotranspiration rates, to raise the uWF values of the areas located in the southern Cerrado, southern Mata Atlantica and Pampa where exports are handled by Bunge, Louis Dreyfus and Bianchini.

Table 4.3.7: Comparison between the yield percentiles relative to the 10%, 25%, 50%, 75%, 90% of production for the analyzed companies

Company (-)	**yield(10%)** $(tonnes/ha)$	**yield (25%)** $(tonnes/ha)$	**yield(50%)** $(tonnes/ha)$	**yield (75%)** $(tonnes/ha)$	**yield(90%)** $(tonnes/ha)$
Cargill	0.05	0.15	1.82	2.11	2.48
Cofco	1.78	2.16	2.62	2.76	2.92
Amaggi	2.26	2.45	2.47	2.51	2.73
Bunge	0.79	1.50	1.99	2.57	2.80
Louis Dreyfus	2.13	1.82	2.20	2.84	2.77
Bianchini	1.90	2.28	2.59	2.75	2.87

Figure 4.3.5 shows how at the sub-national scale production is influenced by the climatic parameters embedded in the evapotranspiration process.

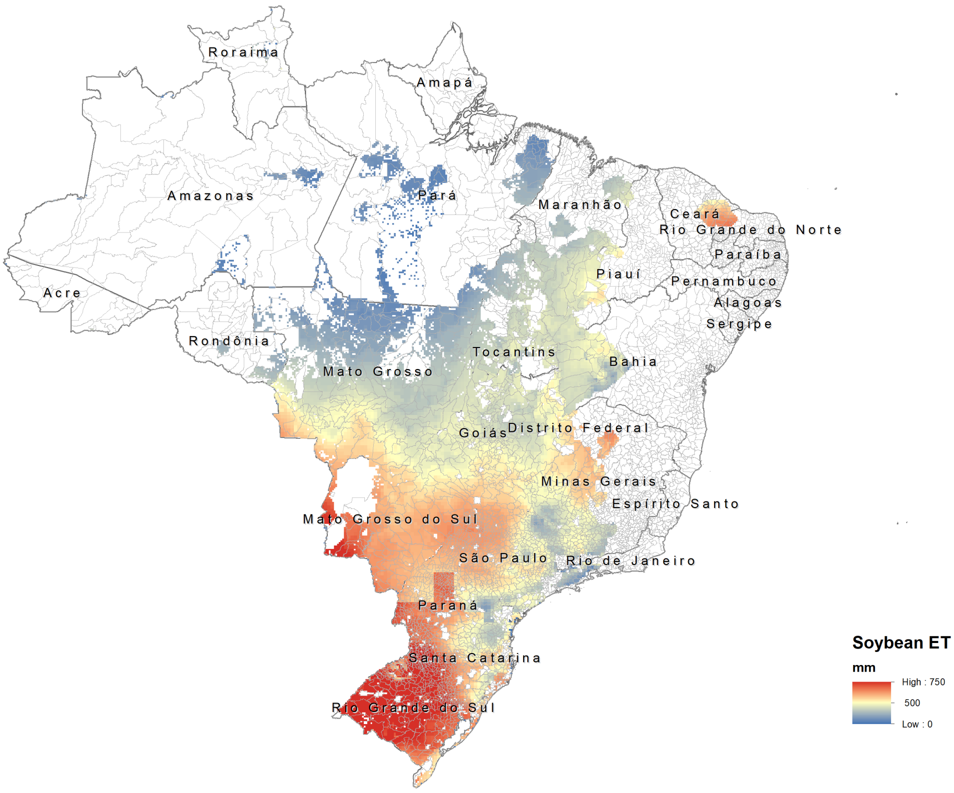


Figure 4.3.5: Evapotranspired water over the Brazilian soybean harvested land for the reference year 2000 (Tuninetti et al., 2015)

4.3.2 Water footprint volumes at the company's scale

Hereafter in figure 4.3.6 it is reported the bipartite network of the volumes of water footprint flowing from sourcing municipalities to Italy, passing trough the handling of the major six exporting companies. The starting point of the flow is represented by the centroids of production, previously represented in figure 4.3.3; the layer on the map represents the WF gradient for each company over the related municipalities; the central column reports the range, distributed over a number of municipalities, of the WF volume calculated (m^3). The flow reaching Italy through these top-trading companies is totally equal to $5.1e + 08$ m^3, coming from 344 traced municipalities - over the 374 identified - and representing the 85% of total WF flow of Brazilian soybean import at the sub-national scale.

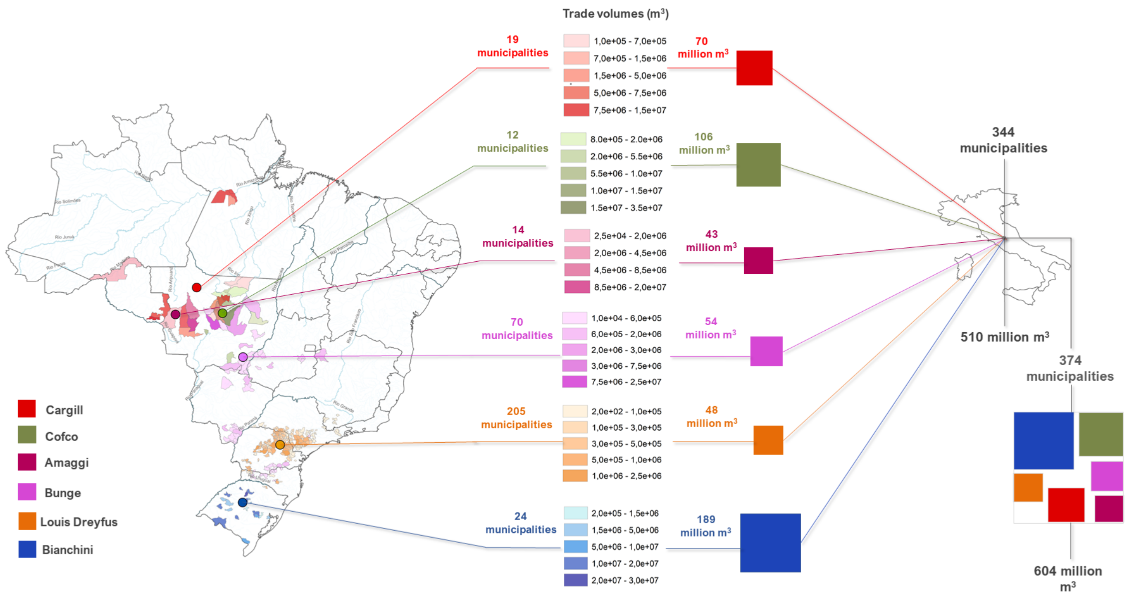


Figure 4.3.6: Bipartite network of the volumes of water footprint flowing from the sourcing municipalities to Italy in 2018, passing trough the handling of the major six exporting companies, set in their weighted centroids of production and over their WF gradient, contributing to 510 million m^3 WF from 344 traced municipalities

The network in figure 4.3.6, highlights also the weight of each company in the Italian incoming WF volume. Figure 4.3.7 shows that: Bianchini holds 31% of the flow, followed by Cofco with 18% and Cargill with 12%; Bunge, Louis Dreyfus and Amaggi have a similar share, respectively of 9%, 8% and 7%. Other exporting companies account for the remaining 15%. But previous results, such as the comparative boxplots in figure 4.3.2, demonstrate that these weights have different meanings:

- Bianchini total WF ($1.89e + 08$ m^3) is the largest volume because it accounts both for the highest uWF values ($m^3/tonne$), derived from climatic patterns which raise the crop water-requirement (m^3/ha), and for the intense rate of production of the related municipalities;

- Cofco accounts for the 18% of the total WF volume, with $1.05e+08\ m^3$ mainly because of the significant amount of soybean exported;
- Cargill and Amaggi, with respectively $7e+07\ m^3$ and $4.3e+07\ m^3$, 12% and 7% of the total flow, despite the fact that their sourcing municipalities are among the most intensive producers, manage to not explode in the WF volumes due to low uWF values characterizing the areas where they hold the export;
- Bunge, with a very extended sourcing production and a weight of the 9% in the total WF volume, stands in the middle range, being characterized by not either an intensive production nor intense uWF values, even if these are higher in the southernmost sourcing municipalities which reach the latitudes shared by Louis Dreyfus and Bianchini. Indeed, as can be seen from the gradient in figure 4.3.6, these southern municipalities show the lowest WF range for Bunge, being thus characterized by no intense production rates. But the overall production makes Bunge account for a WF volume anyway greater than that of Louis Dreyfus;
- Louis Dreyfus, even though it accounts for high uWF values, smooths its WF exporting volume, $4.8e+07m^3$, thanks to the lower quantity of tonnes involved in the export with respect to the other main traders, contributing to the 8% of the total WF volume.

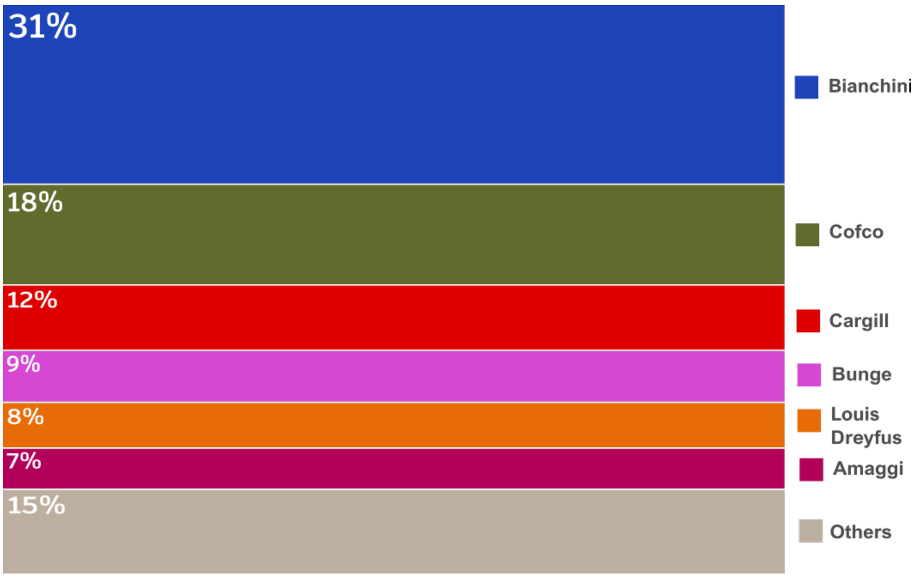


Figure 4.3.7: Companies' weight in the virtual water trade to Italy from Brazilian municipalities

Table 4.3.8: Water footprint volumes and anthromes of analyzed companies

Company (-)	**Blue** WF (m^3)	**Green** WF (m^3)	**Total** WF (m^3)	**Prelevant anthrome** (-)
Bianchini	3.92 E+05	1.88 E+08	1.89 E+08	Populated rangelands
Cofco	6.62	1.06 E+08	1.06 E+08	Remote forests
Cargill	2.80 E+02	6.96E+07	6.96 E+07	Remote forests
Bunge	3.30 E+02	5.42E+07	5.42 E+07	Remote forests
Louis Dreyfus	2.96 E+03	4.79 E+07	4.79 E+07	Residential rainfed mosaic
Amaggi	1.34 E+02	4.32 E+07	4.32 E+07	Remote forests

Table 4.3.8 shows also that Bianchini is the exporter group weighting the most in blue water trade, accounting for the 86% of the total $4.57e + 05m^3$ This result highlights that the blue WF volume is essentially embedded in Bianchini except for about 14% accounted by all other minor companies. The green WF is unpacked among exporter companies in much the same way of the total WF volume, due to the huger weight it represents overall in comparison with the blue WF. The prevalent anthromes in this case represent the most frequent category throughout each state, though the map in figure 4.1.11 gives a more accurate framework of the anthromes at the municipality scale. Overall, the whole flow exported by companies trading with Italy amounts to $6.042e + 08m^3$ compound by $6.037e + 08m^3$ of green water and $4.57e + 05m^3$ of blue water.

4.4 Virtual water flows destinations in domestic utilization pattern

This last section of results illustrates the outcome expected for the imported soybean from the Brazilian municipalities and companies analyzed in the Italian supply, through the new Food Balance Sheets by FAOSTAT for the year 2018, FAOSTAT (c) detailed trade matrix for 2018 and FAOSTAT (a) production statistics for 2018. The Sankey Diagram in figure 4.4.1 shows how the Italian supply is distributed over all the possible patterns of utilization. This analysis served to model the behaviour of the allocation, allowing to quantify how the import from the analyzed top-trading companies is redistributed in the Italian facilities. As explained in chapter chapter 3, the FBS refers to primary soybean, the path of cake is considered stand-alone and it is included in the utilization allocation through a direct connection with the processed items. The diagram draws the path of primary soybean and of soybean cake imported from Brazil. The total supply of primary soybean, $2.8e + 06$ *tonnes* is compound by production (41%) and import (59%); of this import the 10% is purchased from the Brazilian municipalities analyzed, accounting for 1.73e+05 tonnes, quantity that represent the 57% of total soybean equivalent exported from these municipalities. The major six trader companies at study contribute to the flow of primary soybean almost to the 88%, with 1.51 $e + 05$ *tonnes* exported.

Still looking at the primary soybean unpacking through the FBS in figure 4.4.1, it emerges that almost all the utilization slots split into the Domestic Supply quantity (94%), while less than 1% flow to Export and the 4.9% is stocked. Among the Domestic possibilities of utilization, the Processing sector dominates accounting for more than the 91% of the supply. Feed is the one purchasing the most (4.9%) between the remaining options where stand also Food, Seed and the Losses. The Processing manufacturing results focused on Soybean Cake, which provides the 84%, while to Soybean Oil is addressed the remaining 16%.

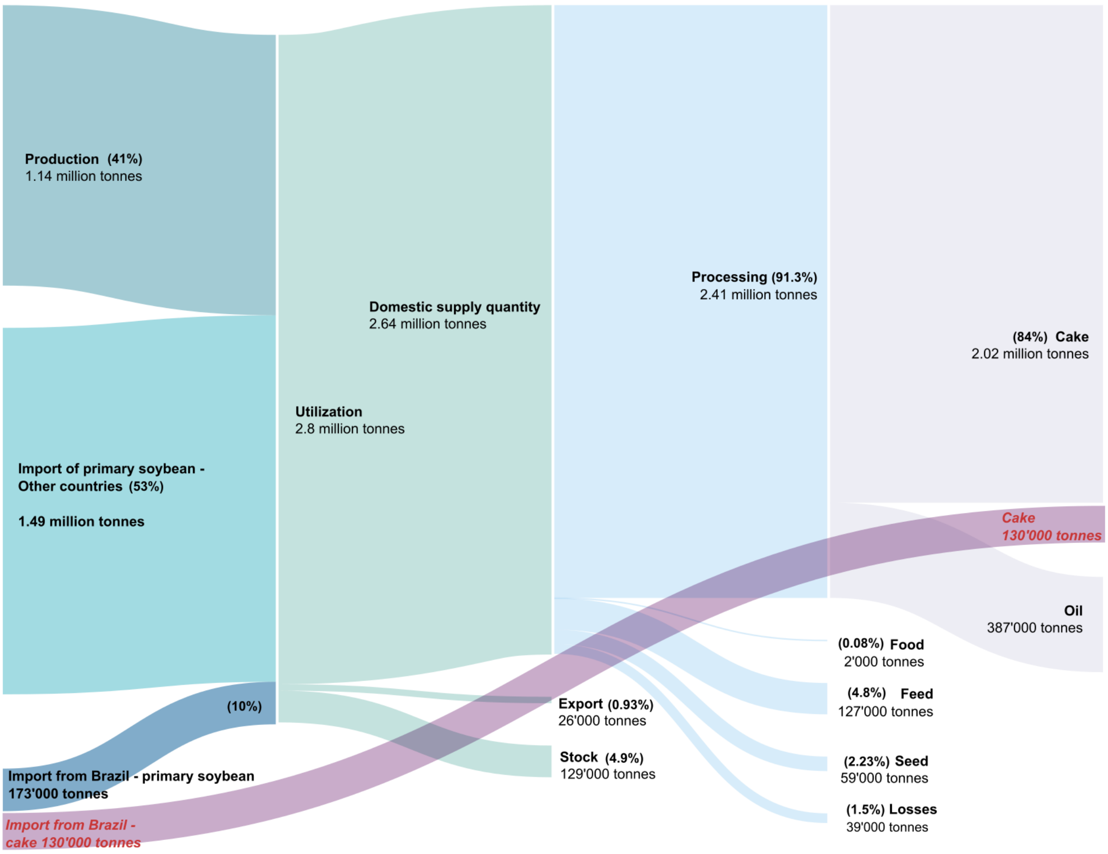


Figure 4.4.1: Italian soybean equivalent supply in 2018. Integration of the new Food Balance Sheet for soybean in 2018 FAOSTAT (b), with the import data of soybean cake from Brazil in 2018 FAOSTAT (c) and with the sub-national trade values at study

Results show that the Italian supply for primary soybean ends into five possible utilization: oil, cake, food, feed, and seed, respectively being the 15%, 78%, 0.1%, 5%, 2% of the domestic supply quantity. This percentages, combined with the weight in the Italian Import sourcing from Brazil of each trader analyzed, as in (3.4.18) are reported in the Alluvial Diagram in figure 4.4.2: Amaggi accounts for the 14%, Bianchini the 39%, Bunge the 16%, Cargill the 24%, Cofco the 36%, Louis Dreyfus the 13%, represented in the source nodes of the diagram. The target nodes represent instead the weight in this supply of the five possible final utilization patterns, proportionally to the weight they have in the domestic supply utilization. Proportions among commodities do not change between companies: the weight is related to the amount of production purchased overall, thus, each company has the same possibility to provide one of the five commodities: the proportions are drawn by the Italian supply trend shown in figure 4.4.1. Thus, figure 4.4.2 provides the weighted allocation of the utilization commodities in the import of primary soybean from the analyzed companies, proportionally to the Brazilian import.

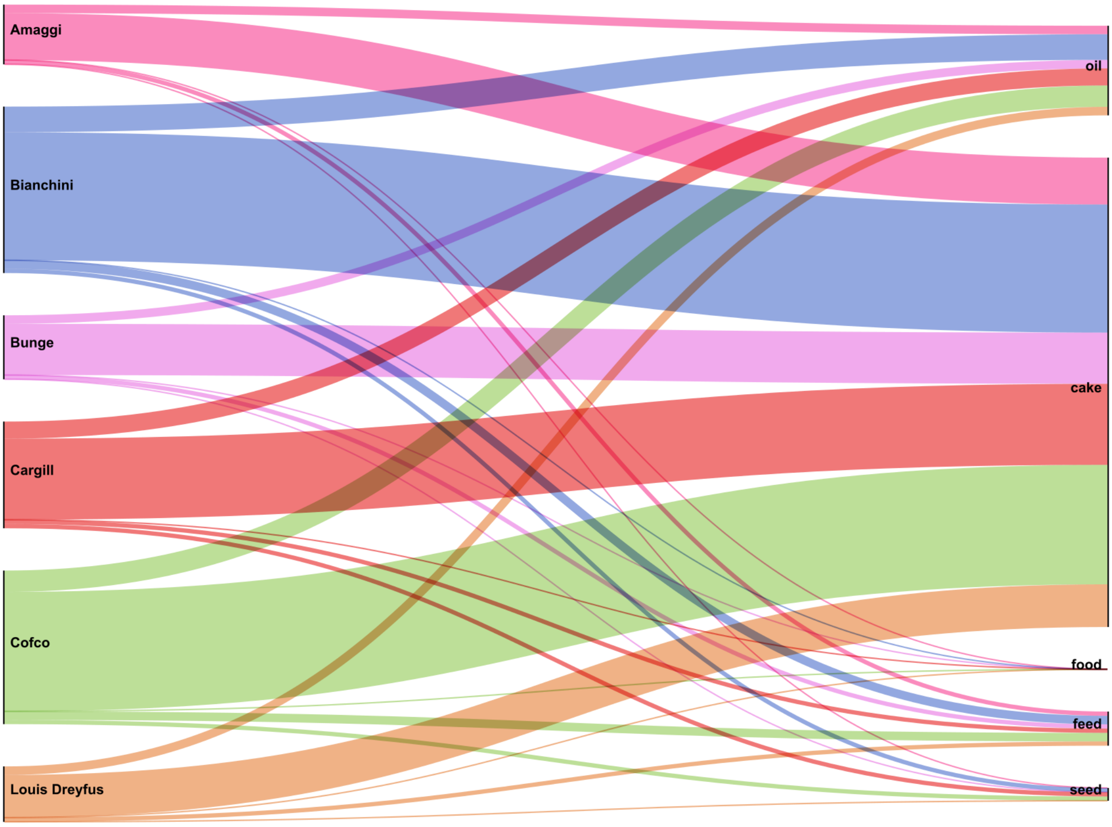


Figure 4.4.2: Combined proportion of six major trading companies in the Brazilian import of Italy and of the weighted allocation of the possible utilization items of the primary soybean path in the Italian supply for 2018

Results shows also that the WF volumes of companies are distributed over the possible primary soybean allocations in the Italian domestic supply as reported in table 4.4.1

Table 4.4.1: Allocation of the WF volumes of the analyzed companies to the utilization products identified in the Italian primary soybean domestic supply through FAOSTAT (b) FBS in 2018

Product (-)	**Amaggi** (m^3)	**Bianchini** (m^3)	**Bunge** (m^3)	**Cargill** (m^3)	**Cofco** (m^3)	**Louis Dreyfus** (m^3)
	Amaggi	Bianchini	Bunge	Cargill	Cofco	Louis Dreyfus
oil	6.48E+06	2.83E+07	8.14E+06	1.04E+07	8.14E+06	8.14E+06
cake	3.37E+07	1.47E+08	4.23E+07	5.43E+07	4.23E+07	4.23E+07
food	3.46E+04	1.51E+05	4.34E+04	5.57E+04	4.34E+04	4.34E+04
feed	2.16E+06	9.44E+06	2.71E+06	3.48E+06	2.71E+06	2.71E+06
seed	9.51E+05	4.15E+06	1.19E+06	1.53E+06	1.19E+06	1.19E+06

The same approach, lead for the soybean cake import, given as explained in chapter 3, produced the following results. Table 4.4.2 reports the weight of the analyzed companies in this trade and the related WF volume.

Table 4.4.2: Analyzed companies weight among the cake export toward Italy from traced municipalities in 2018

Company (-)	Weight (-)	WF (m^3)
Amaggi	0.18	7.85E+06
Bianchini	0.52	2.23E+07
Bunge	0.21	9.21E+06
Cargill	0.32	1.37E+07
Cofco	0.48	2.07E+07
Louis Dreyfus	0.17	7.32E+06

Finally, summing the achieved results, the major six trader companies' WF volumes, allocated among the the Italian supply, both derived from direct import of the processed item or from the possible utilization paths of primary soybean once imported, for 2018 are first shown in figure 4.4.3 and then represented in figure 4.4.4, pin in the weighted centroids of production and overlaid to the prevalent anthromes of each federal state.

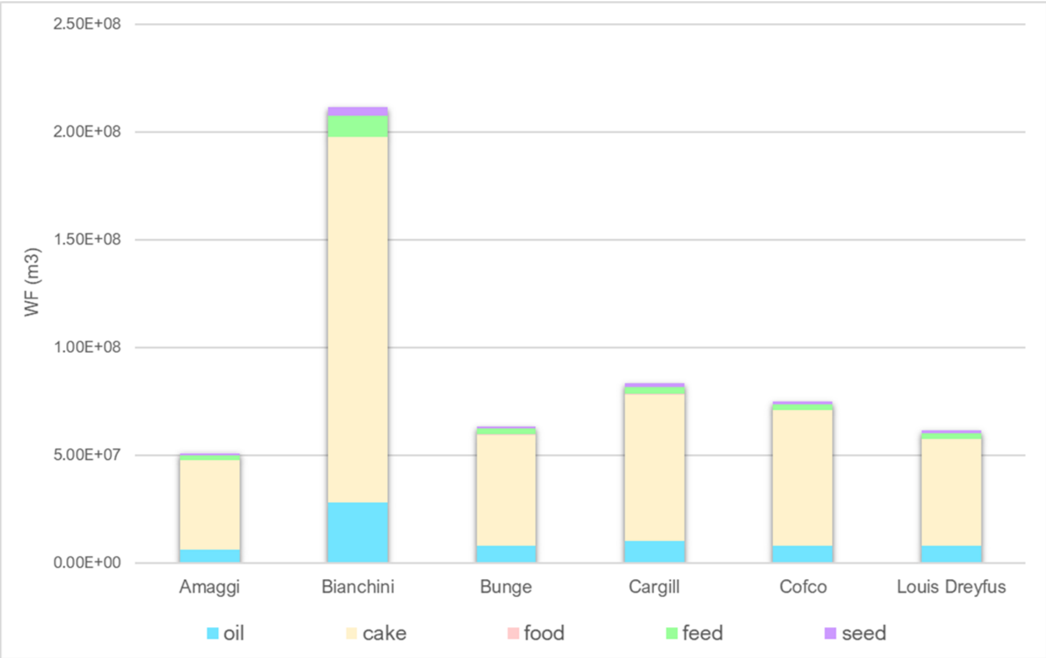


Figure 4.4.3: WF volumes at the company's scale allocated in the Italian Domestic supply for the year 2018, including both the possible utilization features of the imported soya beans and the import of already processed soybean cake

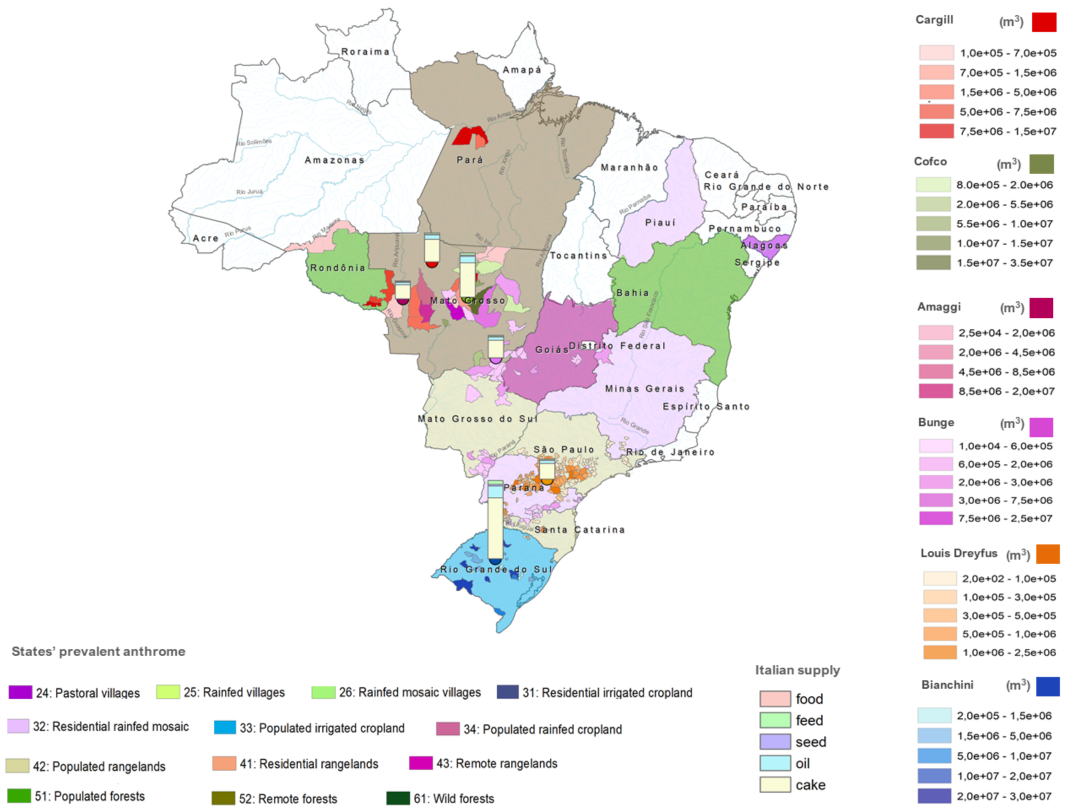


Figure 4.4.4: Water footprint of Italian soybean utilization products throughout the analyzed companies, set in the weighted centroids of production and overlaid to the WF gradient per company and to states' prevalent anthromes

4.5 Comparison of water footprint with other studies

Table 4.5.1: Comparison of water footprint trade volumes at the national and sub-national scale

	Green VWT (m^3)	Blue VWT (m^3)	Total VWT (m^3)
National scale (CWASI)	9.48 e+08	3.48 e+05	9.48 e+08
Sub-national scale	6.39 e+08	4.79 e+05	6.40 e+08

The reasons why the VWT resulting at the sub-national scale of production slightly variates, even if comparable, to the VWT at the national scale by Tamea et al. (2020) may lay in the data limitations exposed in chapter chapter 2. Indeed, the 20% of the Brazilian export to Italy in 2018 results untraced - sourced from unknown municipalities - in Trase database, have been excluded in this assessment, which focuses more on the local WF features than on the global volume involved. Thus, the 20% of the loss export corresponds to 7.6e+04 tonnes. Moreover, 23 municipalities and their overall production, equal to 6.94e+03 tonnes, is lost in the merging between **?** data and uWF values (Tuninetti et al., 2015). Therefore, globally there are 8.29e+04 untraced tonnes. Multiplying this production to the average total uWF among traced Brazilian municipality -2.29e+03 $m^3/tonnes$ - it is obtained a WF equal to 1.90e+08 m^3. Summing the traced volume of WF with the approximated medium value for the untraced municipalities, it is obtained a WF volume of 8.30e+08 m^3. The variation between this volume and that from CWASI, (Tamea et al., 2020) results of the 4%. This comparison shows that the two results are comparable, though recurring to the average medium uWF at the municipality scale smoothes all the environmental diversities highlighted in this study, suggesting the need to consider a confidence level within that 4%.

Chapter 5

Discussion

Results show overall how the Brazilian soybean production is projected toward an increasing exposure to natural resources depletion and climatic risk, in different ways. Firstly, deforestation concurs to long-term effects on the hydrological cycle through modification of the ground surface albedo and thus modifying the rainy period and decreasing the soil capability of moisture retaining. This causes an increase in the need of blue water for irrigation, even in areas, detectable at the municipality scale, not characterized by rain deficit or arid climate, in order to maintain specific yields. Secondly, the rate of production and the single-crop system have already impoverished the soil, thus driving to an expansion of "new" harvested land. Moreover, monocoltures and the intense recourse of pesticides and herbicides causes massive pollution of water and soil, loss of ecosystem services provided by native biodiversity. The rush to new harvested land spread soybean croplands conversion also in regions where the climatic sustainability for soybean crop shows the lowest level at a country scale as shown in the second panel of figure 5.0.1. The climate zones and the potential yields from Licker et al. (2010) suddenly highlights an evident deviation of North- Central Eastern region from the medium-high climatic potential yield of the other regions cultivating soybean in 2000. That area comprises the region of MATOPIBA, at the intersection of Maranhão, Tocantins, Piauí and Bahia states in the Cerrado ecoregion where between 2010 and 2015, soy exports doubled, from 3.5 to 7.1 million tons Trase (2018b).

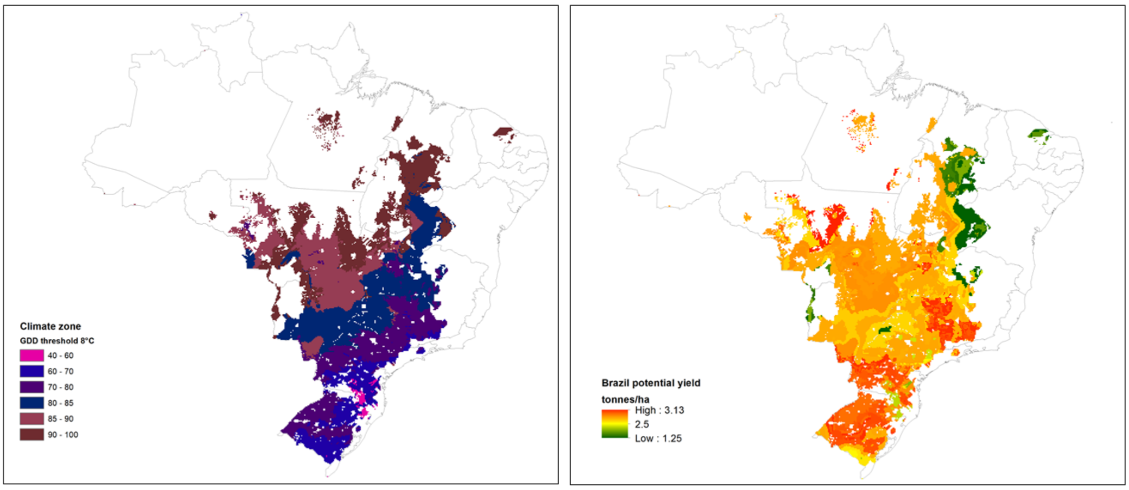


Figure 5.0.1: Brazil climate zone in GDD and climatic potential yield for soybean in 2000

The municipality of Correntina in the Italian study case finds itself at the transition between low and medium potential yield and different climatic zones. The boosting of soybean harvest in this location evidently pushed to blue water exploitation and related rising competition between domestic and agricultural use, as illustrated in the first section chapter 4. Regions such as the inner Mato Grosso or the states of Santa Catarina and Rio Grande do Sul, shows high climatic potential yield, but the variables on the table are multiple and the exponential forcing of the system is represented by the increasing market demand. Rio Grande do Sul is for example subjected, along with the state of Bahia, to a intensive irrigation plan scheduled for 2030 (ANA, 2017) and is exposed more to water climate risk Pousa et al. (2019). Also, the estimated yield gap in 2000, mapped in figure 5.0.2, shows a tendence to colosing the gap already at that time, with major potential at the border between Tocantis, Bahia, Goias, southern-east areas in the Atlantic Forest and in the southern state of Rio Grande do Sul. The current yield at the national scale by FAOSTAT (a) for Brazil, suggest the gap is going to a closure, especially through an at cost chemical inputs and increased irrigation. In this chapter, the study will fill the analysis evaluating the Italian climatic potential and current yield gap in order to draw a scenario of re-allocation of the most controversial Brazilian soybean spots of production in the Italian harvested soybean croplands.

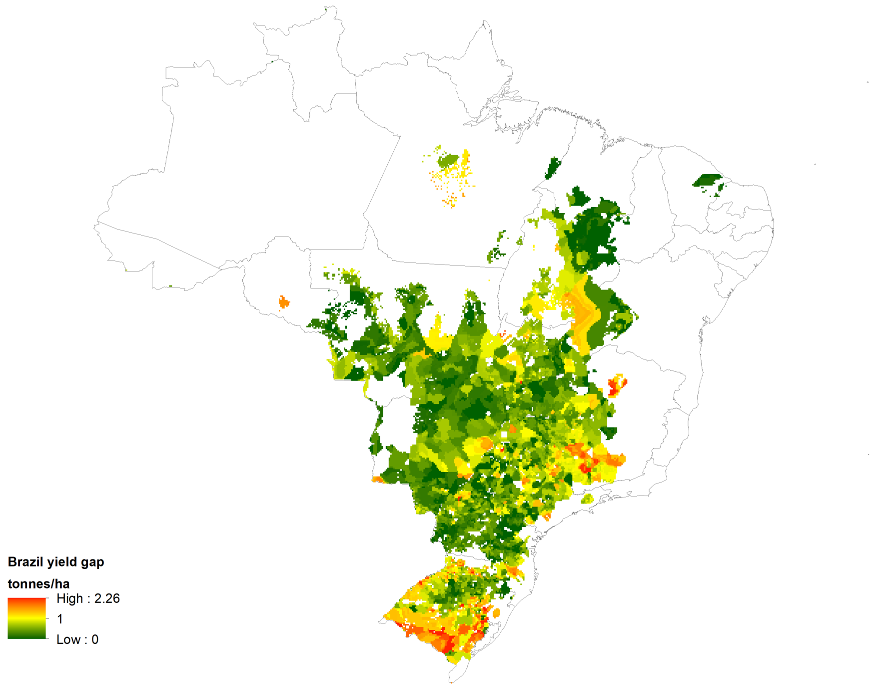


Figure 5.0.2: Brazilian yield gap in 2000 (*tonnes*/*ha*). Difference between the climatic potential yield and the actual yields (*tonnes*/*ha*)

Comparing the first panels of the figures 5.0.1 and 5.0.3 it can be observed that some areas of the Italian territory share the same climatic zone of some cells in the southern Mata Atlantica in Brazil, though over all the ranges between the two countries present a clear shift. Looking at the climatic potential yield in the second panels of figure 5.0.1 and 5.0.3 it emerges that Italy present even higher climatic potential yield than Brazil.

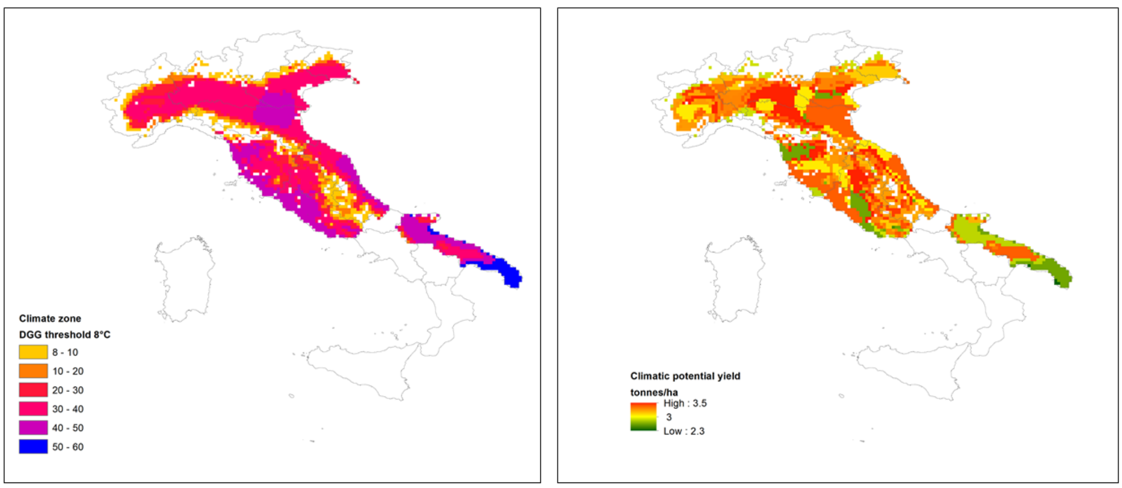


Figure 5.0.3: Italian climate zone in GDD and climatic potential yield for soybean in 2000

The Italian yield gap mapped by Licker et al. (2010) for the reference year 2000, highlights a strong cut between regions. The North-East of the country and part of the inner center present almost yield gap, while the regions of Puglia, Abruzzo, Toscana and then Piemonte and part of Lazio and Marche still shows a degree of improvement.

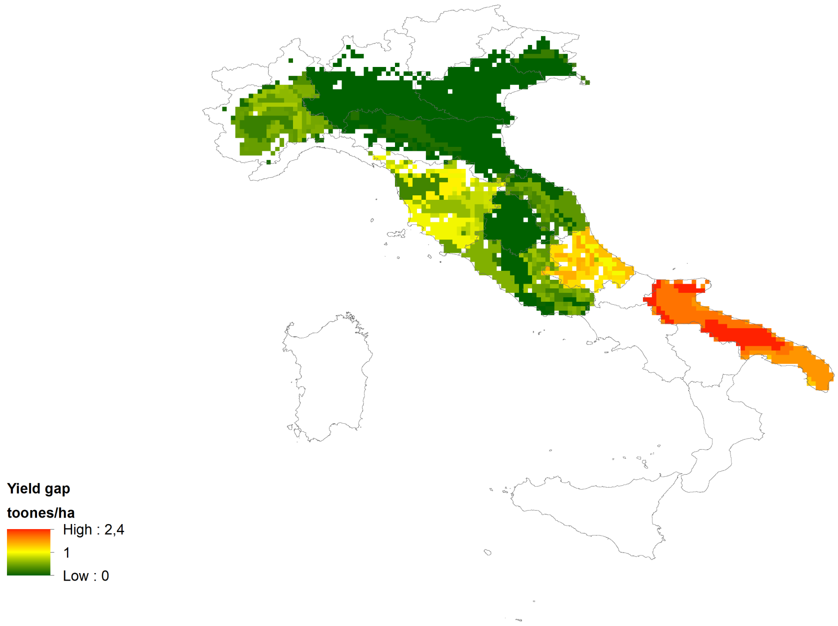


Figure 5.0.4: Italian yield gap in 2000 (*tonnes/ha*). Difference between the climatic potential yield and the yields of 2000 (*tonnes/ha*) by Monfreda et al. (2008)

The current yield of production, referred to year 2020, sourced from **?**, in figure 5.0.5 are represented for the provinces which in 2000 do not present an already closed yield gap, see figure above 5.0.4. The yields are expressed in ranges to better catch the effective heterogeneity between provinces. Surprisingly, Puglia turns out to not harvest soybean since 2012, showing moreover for the precedent years, very small productions and hectares harvested (ISTAT).

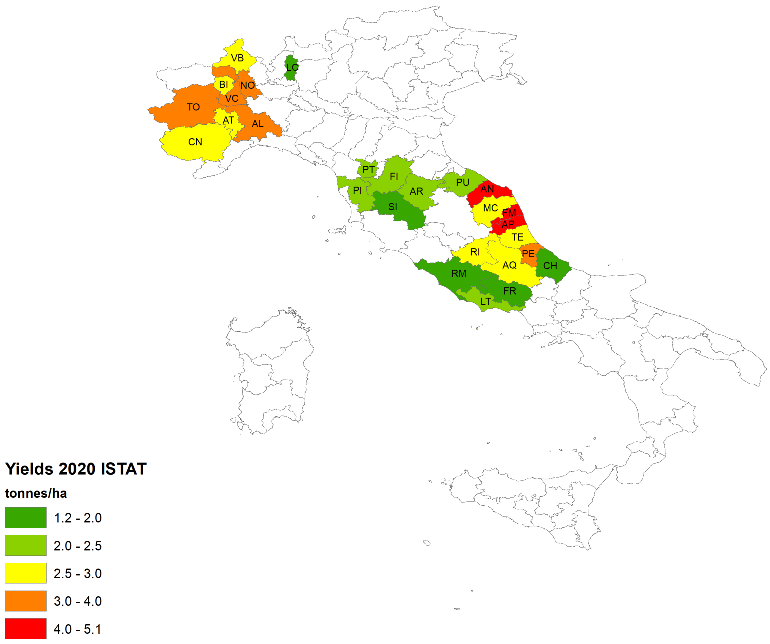


Figure 5.0.5: Yields calculated from the agricultural census by ISTAT for the year 2020 (*tonnes/ha*). All data are surveyed, except for those in the region of Marche, which relies on estimated values of production (*tonnes*) and of harvested land (*ha*).

Figure 5.0.5 reports the calculated yield gap referred to 2020, the latest ended agricultural season. The values of Puglia recorded by Licker et al. (2010) for 2000 have been added to the current yield gap calculated for the other harvesting provinces.

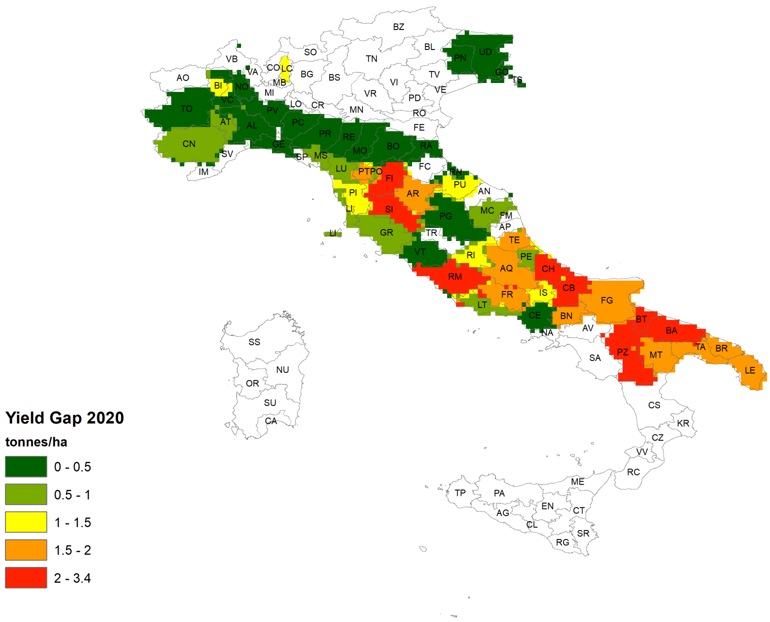


Figure 5.0.6: Italian yield gap in 2020 (*tonnes/ha*). Difference between the climatic potential yield by and the yields surveyed and estimated by ISTAT (*tonnes/ha*) at the province scale. The closed yield gaps are not represented.

To build a more robust estimation of actual yield gap it is calculated the average yield over the latest three years' statistics: the ones of 2018, 2019 and 2020, smoothing the annual fluctuations and then related to the climatic potential yield. The resulting current yield gap is represented in the following figure **??**

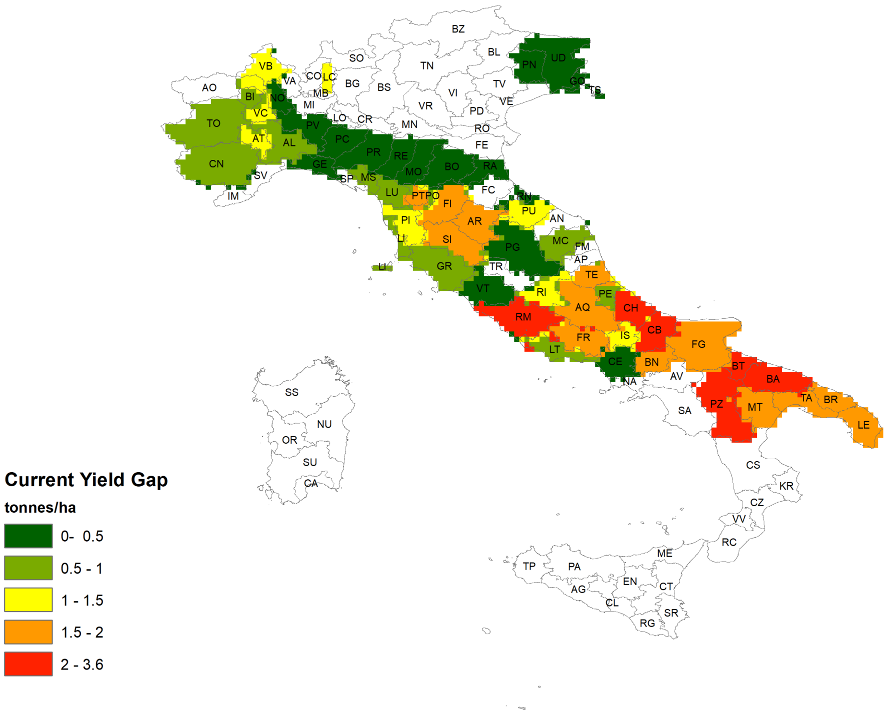


Figure 5.0.7: Current yield gap of Italian soybean production, calculated from the three-years (2018,2019,2020) averaged yield and the climatic potential yield with reference year 2000

Chapter 6

Conclusions

Through the international trade of agricultural goods, water resources that are physically used in the country of production are virtually transferred to the country of consumption. Food trade leads to a global redistribution of freshwater resources, thus shaping distant interdependences among countries. Recent studies have shown how agricultural trade drives an outsourcing of environmental impacts pertaining to depletion and pollution of freshwater resources, and eutrophication of river bodies in distant producer countries (Dalin and Outhwaite, 2019). What is less clear is how the final consumer – being an individual, a company, or a community- impacts the water resources of producer countries at a subnational scale. Indeed, the variability of sub-national water footprint (WF in m^3/tonne) due to climate, soil properties, irrigation practices, and fertilizer inputs is generally lost in trade analyses, as most trade data are only available at the country scale (e.g., FAOSTAT. Flach et al. call for enhancing the Virtual Water Trade assessment through resolute supply-chain mapping methods, as the one provided by Godar et al. (2015), to cope with the loss of the peculiar environmental features available at high spatial resolution. Indeed, most of the agricultural, ecological and climatic datasets are available at 5 arc min grid level, providing a refined environmental framework within spatial variability. Merging these detailed datasets with recent supply-chain mapping method could bring to a higher level every impact assessment of supply-chains. In this thesis the detailed soybean trade between Brazil and Italy has been assessed through the latest version of the Spatially Explicit Information on Production to Consumption Systems model (SEI-PCS) introduced by Godar et al. (2015). This study provides detailed data on single trade flows (in tonne) along the crop supply chain: from local municipalities- to exporter companies- to importer companies – to the final consumer countries. These data allowed us to capitalize on the high-resolution data of agricultural WF available in the literature, in order to quantify the sub-national virtual water flows behind food trade. Results revealed that the Brazilian soybean flow reaching Italy can be traced back to 374 municipalities with heterogeneous agricultural practises and water use efficiency. Results also shown that the largest flow of virtual water from a Brazilian municipality to Italy -3.52e+07 m^3 (3% of the total export flow)- comes from Sorriso in the State of Mato Grosso, leader of soybean production worldwide, completely accounted by green water. Conversely, the highest flow of blue water -1.56e+05 m^3- comes from Jaguarão, in the State of Rio Grande do Sul, located in the Brazilian Pampa. The municipality of Correntina in the state of Bahia (Central-Eastern Brazil) emerges as a critical supplier due to the blue water exploitation. On the Western side, conversely, municipalities in the states of Parana and Mato Grosso stand out for their rapid conversion from Populated or Remote Forest to soybean croplands. These productions do not affect directly blue water resources in the same way of Correntina or as the municipalities in the Southern state of Mato Grosso, but concur indirectly to the decrease of green water availability for crop growth. Indeed, the albedo of the ground is modified by the different vegetation cover, the soil is impoverished with respect to native vegetation and in the light of poor crops' rotation. These factors concur to modify the rainy onset (Leite-Filho et al., 2019) and the moisture availability in the soil for crop complete evapotranspiration during the growing period. The long-term effect is a growing need of blue water also in areas usually characterized by abundant rainfalls and green water availability. The irrigation plan exposed in the ANA shows an exponential increasing in the irrigated area in Brazil within 2030. Thus, even though at the country scale the soybean production of Brazil is supported by green water, at the municipality scale analyzed in this thesis, water-related issues interconnected with deforestation risk Trase (2018b), Trase (2020) and economic patterns of trade, peculiar for each importer country, emerge. In fact, the study highlights a *regionality* of the supply of the main European importer countries. Not all the importer countries analysed in this study import soybean from the main regions, that can be separated to a distance similar of that between Stockholm and Rome or Paris and Tunisi. This regional trend of the import supply is hidden in the trade commitments of each country with some trader companies. In this framework, the other objective of the study was to connect the local productions to the domestic importer supply by means of the detection of the exporter companies. The analysis at the company scale reveals that as many as 38 exporting companies can be identified in the export flows to Italy. Bianchini is the largest virtual water trader (1.88 e+08 m^3 of green water and 3,92 e+06m^3 of blue water), followed by COFCO (1,06 e+08 m^3 of green water and 6.62 m^3 of blue water), and Cargill (6.96 e+07 m^3 of green water and 2.80 e+02 m^3/tonne of blue water). The water efficiency and the geography of the VWT from the top six exporting partners is assessed in details. What emerges is that, the uWF at the company's scale is more influenced by the climatic patterns, with respect to the uWF at a country-scale whose variability, conversely, is mainly driven by yields (Tuninetti et al., 2015), (Tuninetti et al., 2017), (Tamea et al., 2020). This outcome confirms the relevance of considering sub-national variations when assessing the VWT of import, to enhance the policy management of sustainable supply-chains Gardner et al. (2019). By assessing the production's impacts at the municipality scale, the municipality of Correntina emerged as a rising critical spot of irrigated soybean harvesting, where water resources of the region already show flow rate decreasing or aquifer depletion (Cherlet et al., 2018). Thus, it is possible to conclude that Correntina is a controversial sourcing spot for the Italian supply in terms of water resources exploitation. Notably, the volume embedded in Correntina's production is not handled by the major exporter groups of Brazil, as the other municipalities analysed in this thesis. For the soybean market trade, it is interesting to notice that both export operations and import operations are usually hold by the same trader company. When this does not occur, it is a smaller trader company which manage the export, while one of the major trader companies retail the import flow. This pattern is different, for example, from that of coffee, for which companies' traders dynamics are different and there is a clear distinction between exporter and importer groups. In the specific case of Correntina, the exporter company in year 2018 toward Italy results Terra Santa Agro, while the importer group is Cofco. Indeed, the Cofco's *regional* domain extends over the area of MATOPIBA, (Trase, 2018b) not really involved in the Italian import supply in 2018, except for the isolated but intensive case of Correntina.

Finally, aiming at connecting the VW flow to its final destinations in the importer country, the Italian supply has been investigated through the recent released Food Balance Sheets by FAOSTAT (b) - available for year 2018 - and the trade and production statistics for 2018, FAOSTAT (c),FAOSTAT (a). The VW import from the main six trader companies has been proportionally allocated to each sector in the Italian domestic supply: "Food", "Feed", "Seed", "Oil", "Cake". The final outcomes shows that nearly 80% of the sourced soybean - and its related WF volume of each analyzed trader company- ends in the Italian Utilization patterns as soybean cake, going to the animal feed stock.

Finally, the thesis has analyzed, as a possible solution to limit the further increase of soybean production in Brazil, the yield gap in the how the current Italian production of soybean (Mueller et al., 2012). The potential climatic yield of Italy Licker et al. (2010) results higher than that of Brazil, but still high yields are not homogeneously distributed over the national territory and open yield gaps can be filled in many Italian provinces. This solution should be considered in the context of the Italian water footprint and future climate scenarios, in order to be effectively implemented.

Overall, the present thesis has introduced a new approach to assess water footprint along the entire crop supply-chain. This allowed to capitalized on the recently available data on sub-national trade in order to actually re-connect the final consumer to the origin of his or her impact.

By building the bipartite network of importing companies and municipalities where fluxes originate, we are able to efficiently disaggregate the supply chains, thus providing novel tools to build sustainable water management strategies, as addressed by Godar et al. (2016). Quantifying the WF at issue, can also provide tools to reallocate the most controversial volumes in the Italian domestic production.

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Appendix A

Italy

Table A.0.1: Missed unitary water footprint values

Municipality (-)	**Total uWF** (m^3/ton)	**Production** (*tonnes*)
Ariquemes	0.00E+00	5.73E+02
Rio Crespo	0.00E+00	2.17E+02
Alto Paraíso	0.00E+00	1.85E+03
Candeias do Jamari	0.00E+00	9.36E+02
Cujubim	0.00E+00	7.49E+02
Itapuã do Oeste	0.00E+00	3.08E+02
Regeneração	0.00E+00	8.91E+02
Anadia	0.00E+00	3.02E+02
Campo Alegre	0.00E+00	2.59E+02
Jundiá	0.00E+00	2.86E+02
Junqueiro	0.00E+00	3.79E+02
São Miguel dos Campos	0.00E+00	1.14E+02
Borda da Mata	0.00E+00	9.98E-01
Conceição dos Ouros	0.00E+00	2.91E+00
Extrema	0.00E+00	1.84E+00
Lorena	0.00E+00	1.46E-01
São Roque	0.00E+00	6.24E+00
Almirante Tamandaré	0.00E+00	1.19E+00
Bocaiúva do Sul	0.00E+00	3.57E-01
Bom Jesus do Oeste	0.00E+00	1.70E+01
Entre Rios	0.00E+00	2.15E+01
Tigrinhos	0.00E+00	9.49E+00
Canoas	0.00E+00	8.78E+00
Santa Vitória do Palmar	0.00E+00	3.81E+02
Campos de Júlio	0.00E+00	1.68E+04

Table A.0.2: *WF* volumes for 2018 not detected at the company scale for the analyzed companies due to *uWF* data limitation

Municipality	**Company**
ARIQUEMES	Amaggi
ALTO PARAÍSO	Amaggi
CANDEIAS DO JAMARI	Amaggi
CUJUBIM	Amaggi
ITAPUÃ DO OESTE	Amaggi
CAMPOS DE JÚLIO	Amaggi
CANOAS	Bianchini
ENTRE RIOS	Bunge
RIO CRESPO	Cargill
ALTO PARAÍSO	Cargill
CAMPOS DE JÚLIO	Cargill
BORDA DA MATA	Louis Dreyfus
CONCEIÇÃO DOS OUROS	Louis Dreyfus
EXTREMA	Louis Dreyfus
LORENA	Louis Dreyfus
SÃO ROQUE	Louis Dreyfus
ALMIRANTE TAMANDARÉ	Louis Dreyfus
BOCAIÚVA DO SUL	Louis Dreyfus
BOM JESUS DO OESTE	Louis Dreyfus
TIGRINHOS	Louis Dreyfus

Appendix B

Cargill

Table B.0.1: Cargill's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
CEREJEIRAS	1.51E+03	5.17E+03	9.08E+06
CORUMBIARA	1.55E+03	4.33E+03	7.48E+06
PORTO VELHO	1.57E+03	6.75E+01	1.27E+05
VILHENA	1.57E+03	4.33E+03	7.12E+06
MOJUÍ DOS CAMPOS	1.58E+03	2.32E+03	3.99E+06
SANTARÉM	1.64E+03	5.72E+03	9.96E+06
CLÁUDIA	1.64E+03	6.68E+03	1.10E+07
COMODORO	1.69E+03	2.09E+02	3.80E+05
IPIRANGA DO NORTE	1.72E+03	2.25E+03	3.53E+06
LUCAS DO RIO VERDE	1.73E+03	2.30E+02	3.47E+05
MATUPÁ	1.74E+03	4.41E+02	6.92E+05
PEIXOTO DE AZEVEDO	1.76E+03	1.79E+02	2.82E+05
SAPEZAL	1.76E+03	1.96E+03	3.70E+06
SINOP	1.81E+03	3.66E+03	5.68E+06
SORRISO	1.88E+03	8.60E+02	1.45E+06
TANGARÁ DA SERRA	1.89E+03	2.72E+03	4.79E+06

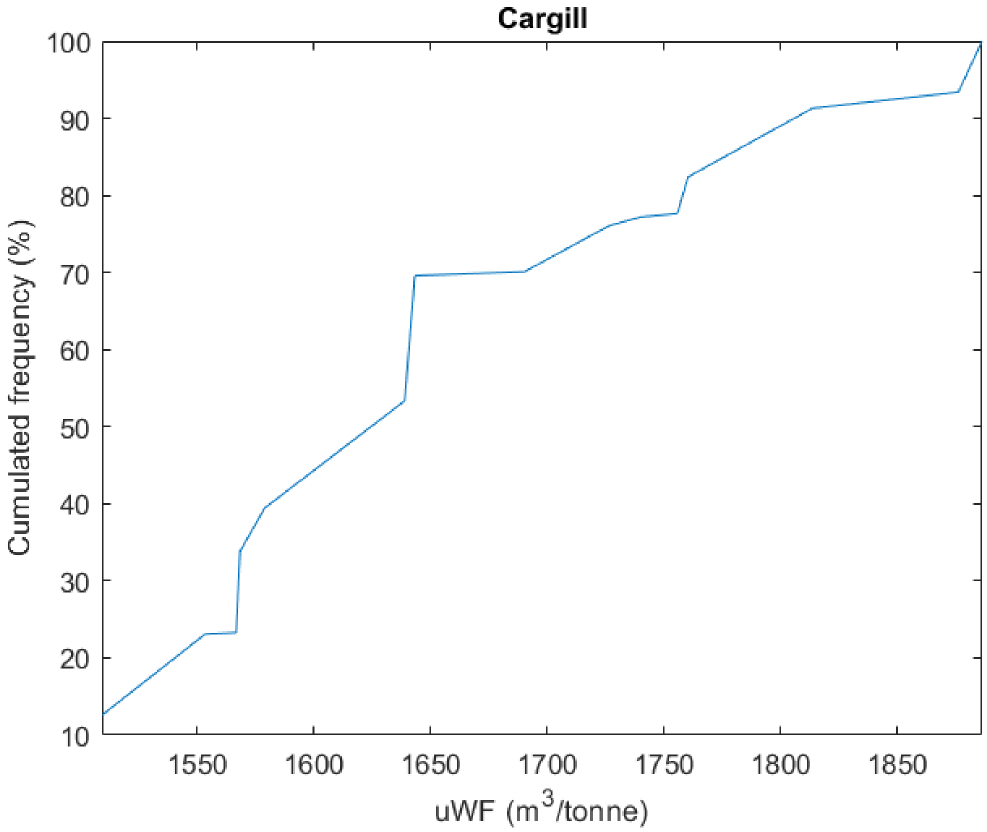

Figure B.0.1: Curve of relative cumulated frequency of uWF ($m^3/tonnes$) over Cargill's sourcing production

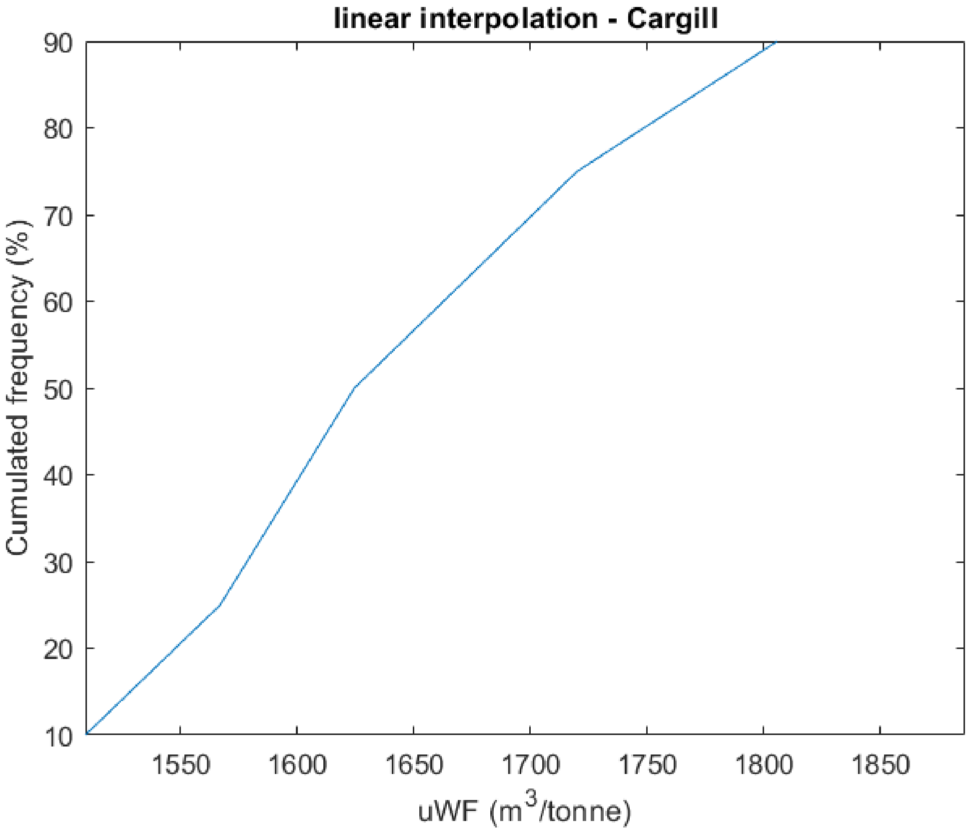

Figure B.0.2: Linearly interpolated curve of relative cumulated frequency of uWF $(m^3/tonnes)$ over Cargill's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

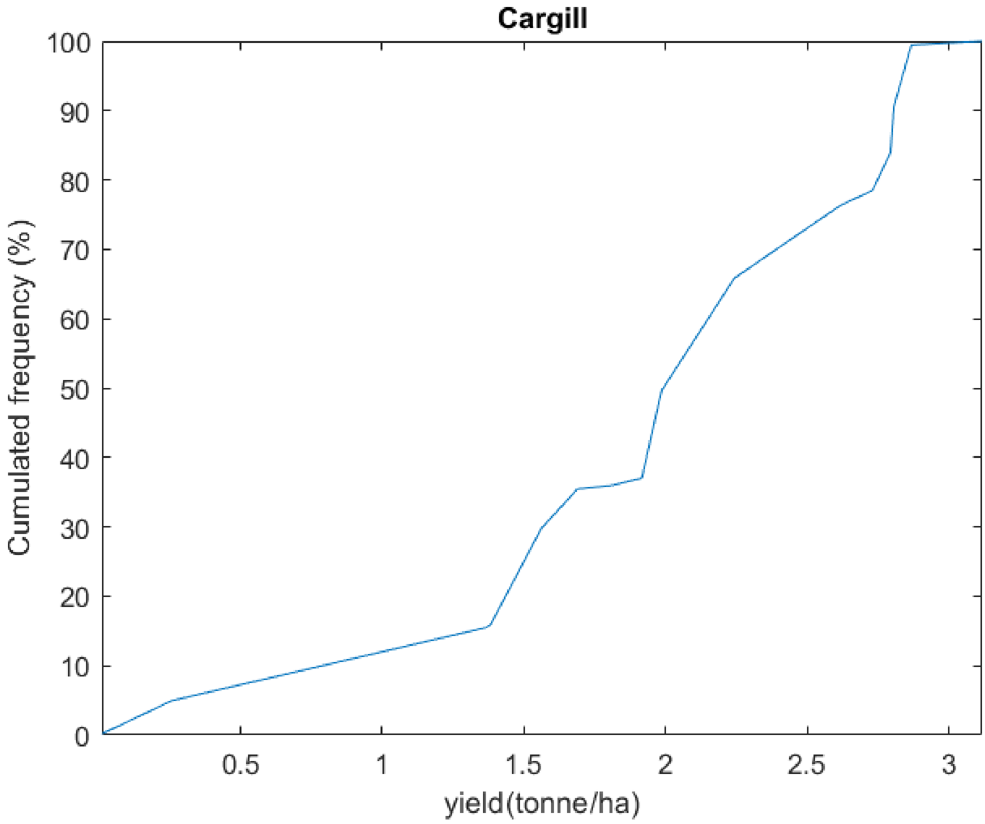

Figure B.0.3: Curve of relative cumulated frequency of yield ($tonnes/ha$) over Cargill's sourcing production

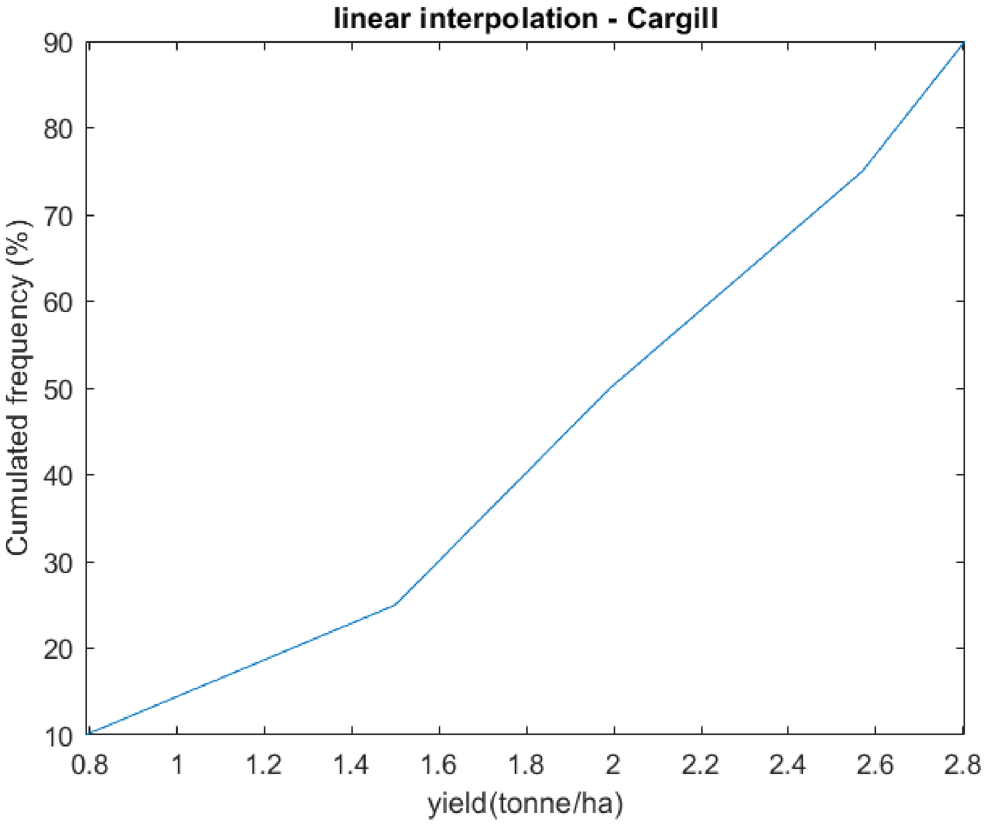

Figure B.0.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Cargill's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

Appendix C

Cofco

Table C.0.1: Cofco's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
CANARANA	1.48E+03	5.00E+02	9.55E+05
CLÁUDIA	1.53E+03	1.24E+03	2.03E+06
IPIRANGA DO NORTE	1.55E+03	5.00E+02	7.83E+05
ITAÚBA	1.57E+03	7.80E+02	1.22E+06
MARCELÂNDIA	1.57E+03	9.50E+02	1.40E+06
NORTELÂNDIA	1.59E+03	5.13E+03	1.01E+07
NOVA SANTA HELENA	1.64E+03	1.37E+03	2.10E+06
NOVA UBIRATÃ	1.69E+03	1.52E+04	2.66E+07
SANTA CARMEM	1.75E+03	4.89E+03	7.78E+06
RONDONÓPOLIS	1.91E+03	2.79E+03	5.49E+06
SINOP	1.97E+03	9.63E+03	1.50E+07
SORRISO	1.97E+03	1.94E+04	3.29E+07

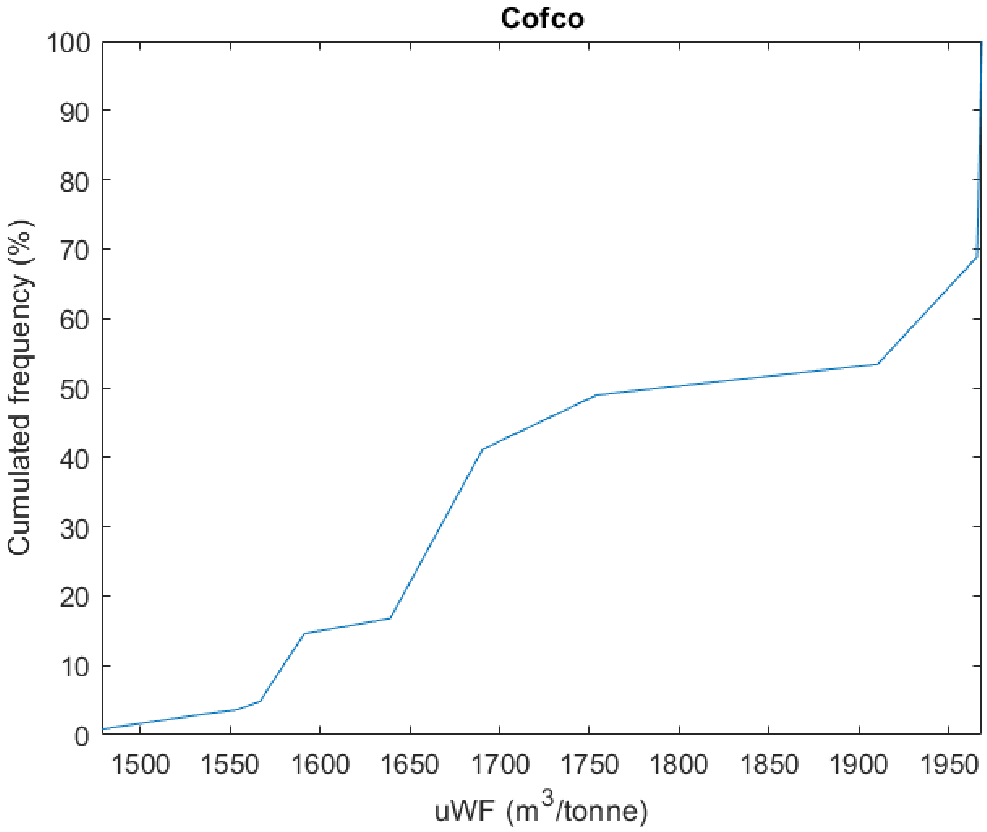

Figure C.0.1: Curve of relative cumulated frequency of uWF $(m^3/tonnes)$ over Cofco's sourcing production

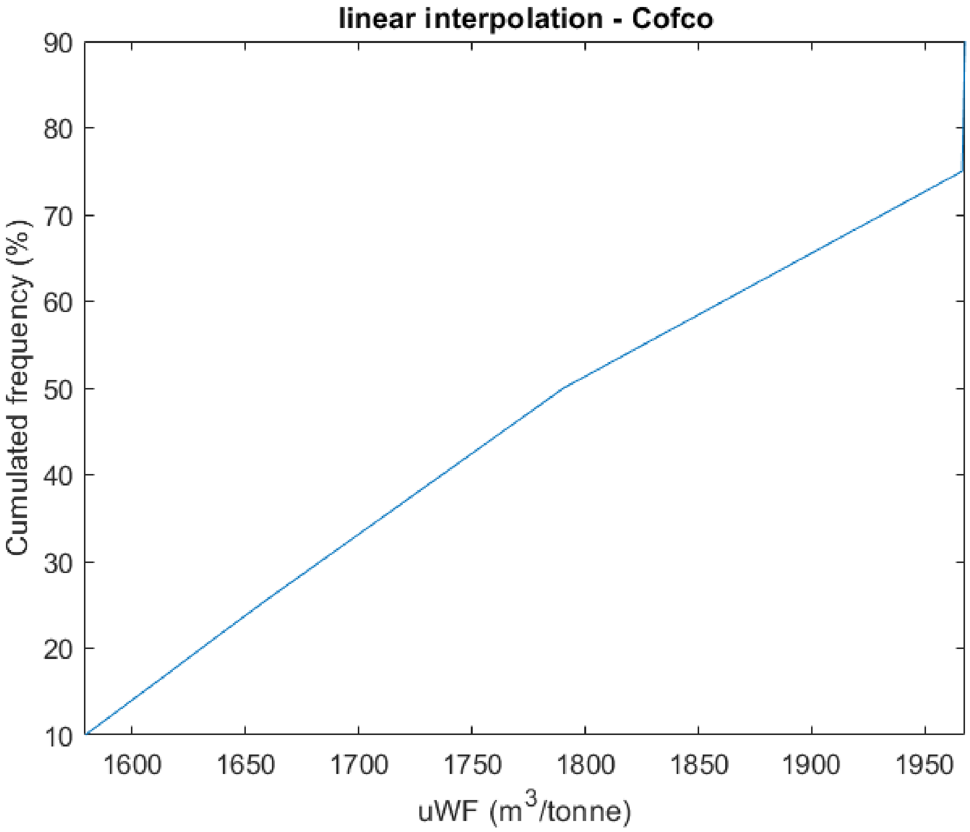

Figure C.0.2: Linearly interpolated curve of relative cumulated frequency of uWF $(m^3/tonnes)$ over Cofco's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

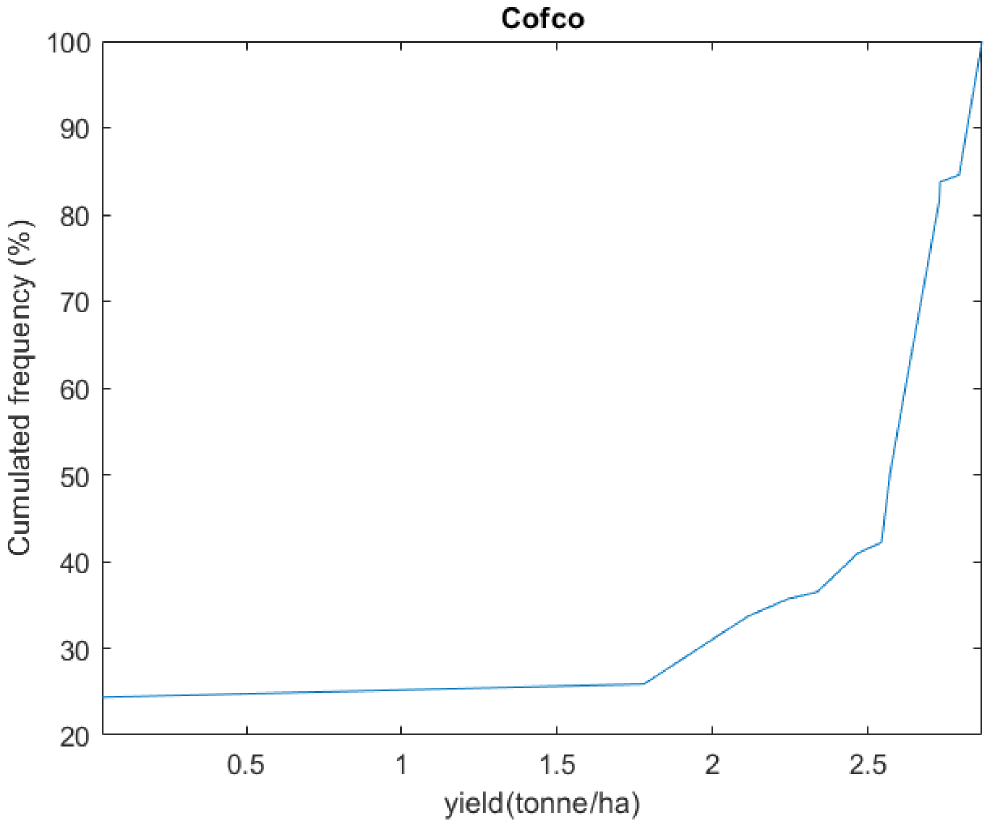

Figure C.0.3: Curve of relative cumulated frequency of yield ($tonnes/ha$) over Cofco's sourcing production

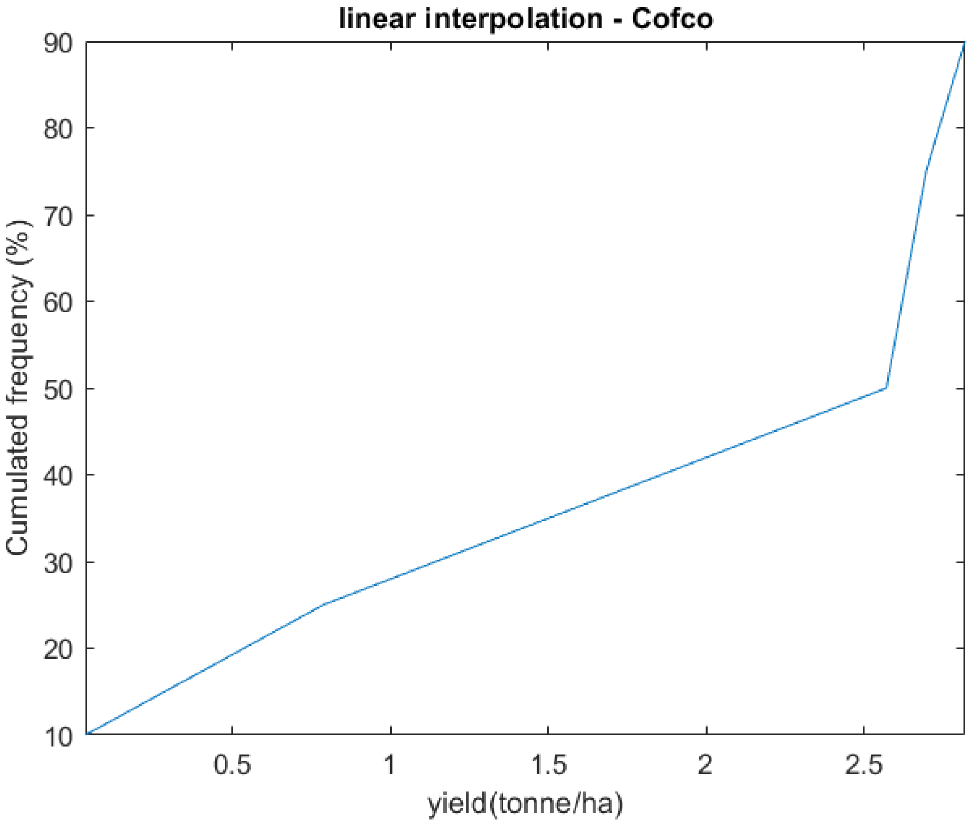

Figure C.0.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Cofco's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

Appendix D

Amaggi

Table D.0.1: Amaggi's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
CEREJEIRAS	1.64E+03	2.72E+03	4.77E+06
CORUMBIARA	1.73E+03	2.27E+03	3.93E+06
PORTO VELHO	1.76E+03	1.13E+03	2.13E+06
VILHENA	1.81E+03	1.99E+03	3.26E+06
BRASNORTE	1.83E+03	2.50E+03	4.56E+06
CAMPO NOVO DO PARECIS	1.88E+03	4.50E+03	8.54E+06
COMODORO	1.89E+03	1.34E+01	2.43E+04
SAPEZAL	1.90E+03	8.48E+03	1.60E+07

Appendix E

Bunge

Table E.0.1: Bunge's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
UNAÍ	1.60E+03	6.68E+02	1.36E+06
TATUÍ	1.66E+03	1.89E+01	5.24E+04
BITURUNA	1.69E+03	3.59E+01	8.29E+04
CRUZ MACHADO	1.76E+03	3.54E+01	8.23E+04
LAPA	1.77E+03	9.22E+02	1.79E+06
MALLET	1.79E+03	2.28E+02	4.13E+05
MARIÓPOLIS	1.80E+03	5.63E+01	1.17E+05
PAULA FREITAS	1.81E+03	2.50E+02	4.80E+05
PORTO VITÓRIA	1.84E+03	5.15E+00	1.03E+04
SÃO MATEUS DO SUL	1.85E+03	4.54E+02	8.03E+05
ÁGUA DOCE	1.85E+03	1.34E+02	3.36E+05
CORDILHEIRA ALTA	1.86E+03	3.34E+00	1.56E+04
CORONEL FREITAS	1.86E+03	3.19E+01	1.29E+05
FREI ROGÉRIO	1.87E+03	2.96E+01	9.72E+04
GALVÃO	1.87E+03	7.45E+01	1.82E+05
IRINEÓPOLIS	1.87E+03	1.95E+02	3.76E+05
MATOS COSTA	1.90E+03	4.83E+00	1.01E+04
MONTE CARLO	1.90E+03	2.80E+01	6.98E+04
NOVA ERECHIM	1.91E+03	1.38E+01	6.72E+04
NOVA ITABERABA	1.92E+03	8.70E+00	4.20E+04
PASSOS MAIA	1.92E+03	1.06E+02	2.71E+05

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
PORTO UNIÃO	1.92E+03	8.41E+01	1.72E+05
QUILOMBO	1.93E+03	7.66E+01	2.85E+05
SANTIAGO DO SUL	1.94E+03	1.66E+01	6.19E+04
TRÊS BARRAS	1.94E+03	1.03E+02	1.93E+05
UNIÃO DO OESTE	1.97E+03	8.05E+00	3.51E+04
VARGEÃO	1.99E+03	9.11E+01	2.20E+05
XAXIM	1.99E+03	7.54E+01	1.88E+05
COSTA RICA	2.04E+03	4.42E+02	9.18E+05
ELDORADO	2.04E+03	7.71E+01	1.49E+05
FÁTIMA DO SUL	2.05E+03	4.12E+01	8.70E+04
GLÓRIA DE DOURADOS	2.07E+03	9.50E+00	2.06E+04
IGUATEMI	2.08E+03	7.62E+01	1.61E+05
ITAQUIRAÍ	2.08E+03	2.34E+02	4.61E+05
JAPORÃ	2.08E+03	1.23E+01	2.67E+04
JATEÍ	2.11E+03	1.39E+02	3.52E+05
JUTI	2.12E+03	1.02E+02	2.31E+05
LAGUNA CARAPÃ	2.12E+03	5.25E+02	1.14E+06
MUNDO NOVO	2.14E+03	4.09E+01	7.66E+04
NAVIRAÍ	2.16E+03	4.76E+02	1.01E+06
PARAÍSO DAS ÁGUAS	2.17E+03	1.65E+02	3.60E+05
RIO VERDE DE MATO GROSSO	2.17E+03	8.59E+01	1.78E+05
SONORA	2.18E+03	3.19E+02	6.04E+05
TACURU	2.18E+03	8.91E+01	2.14E+05
VICENTINA	2.26E+03	4.63E+01	1.09E+05
ALTO ARAGUAIA	2.28E+03	1.28E+02	2.49E+05
ALTO GARÇAS	2.30E+03	2.05E+02	3.81E+05
ALTO TAQUARI	2.31E+03	1.96E+02	3.64E+05
CAMPO NOVO DO PARECIS	2.32E+03	4.00E+03	7.59E+06
CANARANA	2.36E+03	1.03E+02	1.97E+05
GENERAL CARNEIRO	2.40E+03	3.36E+02	6.86E+05
ITIQUIRA	2.41E+03	6.54E+02	1.48E+06
NOVA MUTUM	2.44E+03	1.13E+04	2.10E+07
NOVA XAVANTINA	2.50E+03	1.09E+02	2.36E+05
PARANATINGA	2.50E+03	1.20E+03	3.01E+06
QUERÊNCIA	2.51E+03	4.99E+02	8.27E+05

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
SANTA RITA DO TRIVELATO	2.51E+03	2.26E+02	4.16E+05
SORRISO	2.54E+03	5.38E+02	9.09E+05
TAPURAH	2.55E+03	1.55E+02	2.49E+05
TORIXORÉU	2.77E+03	5.83E+01	1.08E+05
BALIZA	3.29E+03	3.76E+01	7.20E+04
BOM JARDIM DE GOIÁS	3.73E+03	5.26E+01	1.21E+05
MONTIVIDIU	3.74E+03	5.17E+02	9.11E+05
PEROLÂNDIA	4.05E+03	1.00E+02	1.87E+05
PIRANHAS	4.36E+03	8.38E+01	1.79E+05
SANTA RITA DO ARAGUAIA	4.67E+03	2.29E+01	4.57E+04
SILVÂNIA	4.82E+03	3.32E+02	5.97E+05
VIANÓPOLIS	4.86E+03	2.20E+02	3.94E+05

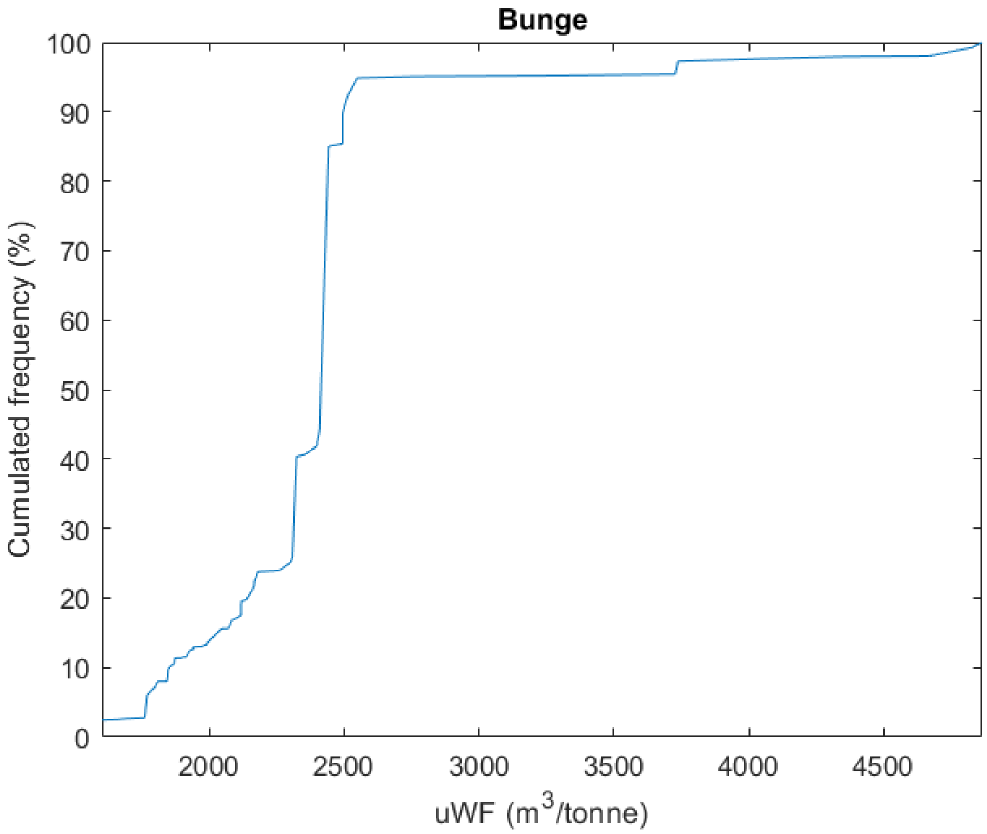

Figure E.0.1: Curve of relative cumulated frequency of uWF ($m^3/tonnes$) over Bunge's sourcing production

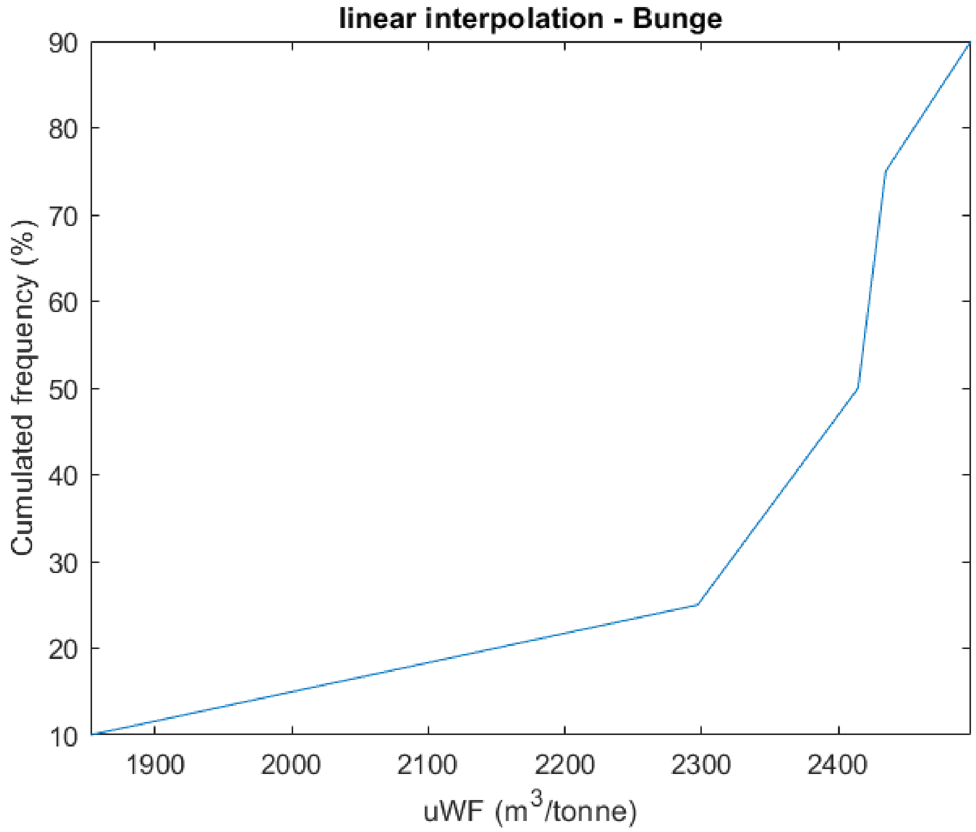

Figure E.0.2: Linearly interpolated curve of relative cumulated frequency of uWF $(m^3/tonnes)$ over Bunge's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

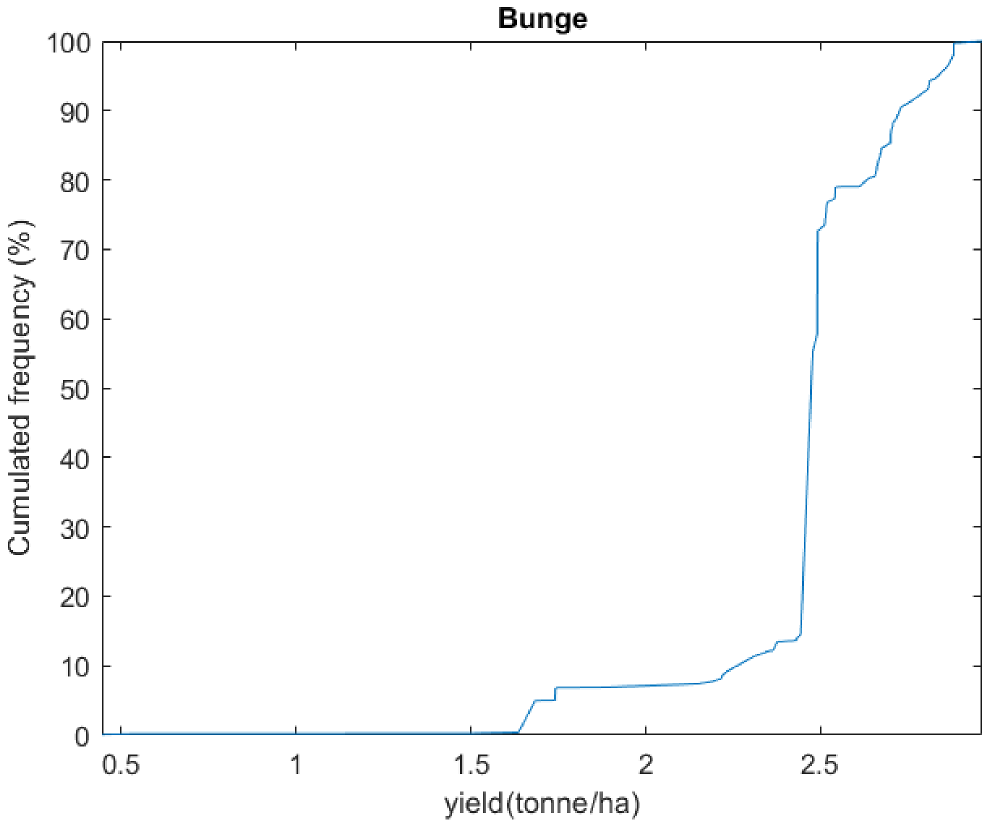

Figure E.0.3: Curve of relative cumulated frequency of yield ($tonnes/ha$) over Bunge's sourcing production

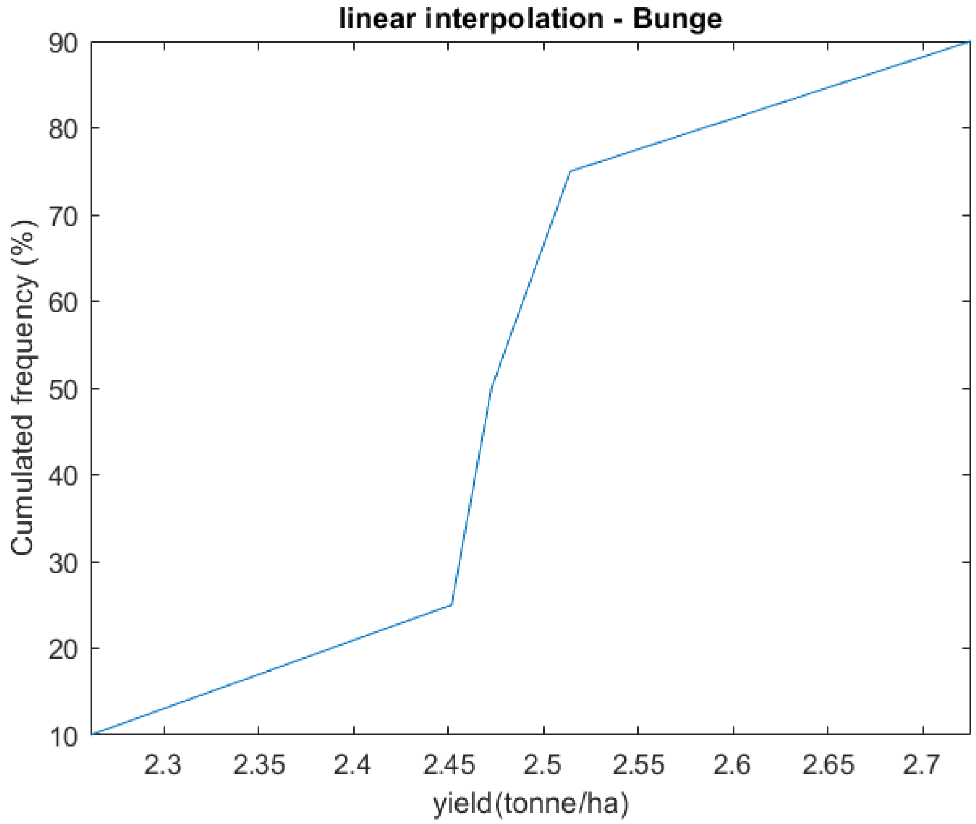

Figure E.0.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Bunge's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

Appendix F

Louis Dreyfus

Table F.0.1: Louis Dreyfus's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
ANDRADAS	1.46E+03	9.98E-01	1.55E+03
CALDAS	1.49E+03	4.37E+00	8.59E+03
CAREAÇU	1.52E+03	5.82E-01	1.52E+03
POÇOS DE CALDAS	1.55E+03	9.01E-01	1.37E+03
SANTA RITA DO SAPUCAÍ	1.63E+03	1.16E+00	2.88E+03
SÃO GONÇALO DO SAPUCAÍ	1.67E+03	3.44E+01	8.90E+04
SÃO JOSÉ DO ALEGRE	1.67E+03	5.82E-01	1.30E+03
SÃO SEBASTIÃO DA BELA VISTA	1.68E+03	3.64E+00	9.71E+03
TURVOLÂNDIA	1.73E+03	7.76E+00	1.98E+04
VARGINHA	1.76E+03	1.46E+00	9.38E+03
ÁGUAS DE SANTA BÁRBARA	1.77E+03	8.32E+01	1.98E+05
ALAMBARI	1.78E+03	5.20E+00	1.32E+04
ANGATUBA	1.79E+03	1.09E+02	3.49E+05
APIAÍ	1.83E+03	9.36E+00	2.33E+04
AVARÉ	1.86E+03	6.88E+01	1.68E+05
BARÃO DE ANTONINA	1.87E+03	2.50E+01	7.07E+04
BOITUVA	1.88E+03	6.24E+00	1.66E+04
BOTUCATU	1.90E+03	2.31E+01	4.83E+04
BURI	1.90E+03	2.91E+02	5.89E+05
CÂNDIDO MOTA	1.92E+03	2.32E+02	5.28E+05
CAPÃO BONITO	1.93E+03	2.96E+02	7.15E+05

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
CONCHAS	1.93E+03	3.36E+00	8.19E+03
CORONEL MACEDO	1.94E+03	5.85E+01	1.37E+05
CRUZÁLIA	1.96E+03	7.64E+01	1.93E+05
ELIAS FAUSTO	1.97E+03	1.82E+00	4.47E+03
ESTRELA DO NORTE	1.98E+03	1.08E+00	2.23E+03
EUCLIDES DA CUNHA PAULISTA	1.98E+03	2.34E+00	6.04E+03
GUAPIARA	1.99E+03	5.61E+01	9.90E+04
IBIRAREMA	1.99E+03	1.16E+02	2.71E+05
ITAÍ	2.00E+03	2.44E+02	5.16E+05
ITAPETININGA	2.02E+03	2.50E+02	5.98E+05
ITAPEVA	2.02E+03	1.18E+03	2.22E+06
ITAPORANGA	2.05E+03	1.13E+02	2.81E+05
ITARARÉ	2.06E+03	2.12E+02	4.16E+05
ITATINGA	2.07E+03	1.34E+01	3.32E+04
JUMIRIM	2.08E+03	3.12E-01	6.93E+02
LARANJAL PAULISTA	2.08E+03	5.11E+00	1.15E+04
MANDURI	2.08E+03	2.68E+01	8.07E+04
MARACAÍ	2.08E+03	6.18E+01	1.58E+05
MIRANTE DO PARANAPANEMA	2.09E+03	3.31E+00	5.72E+03
MOMBUCA	2.09E+03	2.32E-01	5.71E+02
NOVA CAMPINA	2.09E+03	2.36E+00	6.47E+03
ÓLEO	2.09E+03	2.24E+01	6.65E+04
OURINHOS	2.09E+03	3.87E+01	9.91E+04
PALMITAL	2.10E+03	3.19E+02	7.32E+05
PARANAPANEMA	2.10E+03	2.78E+02	7.35E+05
PARDINHO	2.10E+03	1.53E+01	3.04E+04
PEDRA BELA	2.11E+03	1.04E+00	2.17E+03
PIEDADE	2.11E+03	1.39E+00	3.05E+03
PILAR DO SUL	2.12E+03	9.02E+01	2.44E+05
PINDAMONHANGABA	2.12E+03	5.09E+00	1.14E+04
PIRAJU	2.12E+03	8.11E+01	2.34E+05
PORANGABA	2.13E+03	1.37E+00	2.97E+03
PORTO FELIZ	2.13E+03	3.64E+00	8.75E+03
PRATÂNIA	2.13E+03	3.23E+00	6.99E+03
QUADRA	2.13E+03	2.73E+01	5.25E+04

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
RIBEIRÃO BRANCO	2.14E+03	6.65E+00	1.45E+04
RIBEIRÃO GRANDE	2.15E+03	2.50E+01	4.75E+04
RIVERSUL	2.15E+03	3.47E+01	8.52E+04
RIO DAS PEDRAS	2.16E+03	2.30E+00	5.66E+03
ROSEIRA	2.16E+03	8.32E-02	1.82E+02
SALTINHO	2.16E+03	1.70E-01	4.17E+02
SALTO	2.17E+03	1.09E+00	2.65E+03
SALTO DE PIRAPORA	2.17E+03	8.73E+00	2.01E+04
SALTO GRANDE	2.18E+03	7.35E+01	1.85E+05
SÃO LUIZ DO PARAITINGA	2.18E+03	7.49E-01	1.51E+03
SÃO MIGUEL ARCANJO	2.19E+03	1.50E+02	4.51E+05
SÃO PEDRO DO TURVO	2.20E+03	1.09E+02	2.52E+05
SARAPUÍ	2.20E+03	1.24E+01	2.96E+04
SARUTAIÁ	2.20E+03	1.60E+01	4.70E+04
SERRA NEGRA	2.21E+03	1.82E+00	4.13E+03
SOCORRO	2.22E+03	8.73E+00	1.95E+04
SOROCABA	2.22E+03	2.50E-01	5.75E+02
SUMARÉ	2.22E+03	7.28E+00	2.42E+04
TAGUAÍ	2.22E+03	1.03E+01	2.90E+04
TAQUARIVAÍ	2.22E+03	1.37E+02	3.09E+05
TARUMÃ	2.23E+03	4.35E+01	1.15E+05
TATUÍ	2.23E+03	1.09E+01	3.01E+04
TAUBATÉ	2.23E+03	9.57E+00	2.03E+04
TEJUPÁ	2.23E+03	2.76E+01	8.22E+04
TIMBURI	2.24E+03	4.54E+00	1.35E+04
TREMEMBÉ	2.24E+03	5.82E-01	1.30E+03
VARGEM	2.25E+03	3.74E+00	8.23E+03
CHAVANTES	2.25E+03	2.69E+01	6.25E+04
ABATIÁ	2.26E+03	9.35E+01	2.87E+05
ANDIRÁ	2.26E+03	2.08E+02	4.53E+05
ARAPOTI	2.26E+03	4.70E+02	9.06E+05
ARAPUÃ	2.26E+03	1.50E+02	3.12E+05
ARIRANHA DO IVAÍ	2.26E+03	1.68E+02	3.52E+05
ASSAÍ	2.26E+03	2.88E+02	7.36E+05
BANDEIRANTES	2.27E+03	1.97E+02	4.70E+05

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
BARBOSA FERRAZ	2.27E+03	1.55E+02	3.37E+05
BARRA DO JACARÉ	2.27E+03	9.01E+01	2.28E+05
BOA ESPERANÇA DO IGUAÇU	2.27E+03	5.36E+01	1.21E+05
BOA VISTA DA APARECIDA	2.27E+03	7.62E+01	1.73E+05
BORRAZÓPOLIS	2.27E+03	1.80E+02	4.19E+05
CALIFÓRNIA	2.28E+03	9.73E+01	2.11E+05
CAMBARÁ	2.28E+03	1.91E+02	4.29E+05
CAMPO LARGO	2.28E+03	8.87E+01	1.88E+05
CAMPO MAGRO	2.28E+03	4.05E+01	9.44E+04
CÂNDIDO DE ABREU	2.29E+03	2.13E+02	4.69E+05
CAPITÃO LEÔNIDAS MARQUES	2.30E+03	1.06E+02	2.41E+05
CARAMBEÍ	2.30E+03	3.16E+02	4.62E+05
CARLÓPOLIS	2.30E+03	5.89E+01	1.43E+05
CASTRO	2.30E+03	1.02E+03	1.51E+06
CERRO AZUL	2.31E+03	7.42E+00	1.21E+04
CONGONHINHAS	2.31E+03	1.34E+02	3.18E+05
CONSELHEIRO MAIRINCK	2.32E+03	7.76E+01	1.63E+05
CORNÉLIO PROCÓPIO	2.32E+03	4.01E+02	9.10E+05
CORUMBATAÍ DO SUL	2.33E+03	4.12E+01	8.93E+04
CRUZEIRO DO IGUAÇU	2.33E+03	4.87E+01	1.15E+05
CRUZMALTINA	2.33E+03	9.37E+01	1.92E+05
CURIÚVA	2.33E+03	1.18E+02	2.95E+05
FAXINAL	2.34E+03	1.38E+02	2.62E+05
FÊNIX	2.34E+03	1.77E+02	4.20E+05
FIGUEIRA	2.35E+03	3.33E+01	7.76E+04
FRANCISCO BELTRÃO	2.35E+03	2.21E+02	5.16E+05
GODOY MOREIRA	2.36E+03	4.99E+01	1.11E+05
GRANDES RIOS	2.37E+03	3.09E+01	6.60E+04
GUAPIRAMA	2.37E+03	8.25E+01	1.94E+05
IBAITI	2.38E+03	1.20E+02	3.35E+05
IBIPORÃ	2.38E+03	1.95E+02	4.88E+05
IRETAMA	2.38E+03	1.45E+02	3.22E+05
ITAMBARACÁ	2.39E+03	1.41E+02	3.02E+05
ITAPERUÇU	2.39E+03	2.37E+00	5.09E+03
IVAIPORÃ	2.39E+03	2.37E+02	4.95E+05

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
JABOTI	2.40E+03	2.00E+01	4.57E+04
JACAREZINHO	2.40E+03	9.36E+01	2.23E+05
JAGUARIAÍVA	2.40E+03	2.21E+02	3.92E+05
JAPIRA	2.40E+03	6.61E+01	1.63E+05
JARDIM ALEGRE	2.40E+03	1.23E+02	2.57E+05
JOAQUIM TÁVORA	2.40E+03	3.11E+01	7.54E+04
JUNDIAÍ DO SUL	2.41E+03	9.53E+01	2.69E+05
KALORÉ	2.42E+03	1.29E+02	3.10E+05
LARANJAL	2.43E+03	2.62E+01	6.02E+04
LEÓPOLIS	2.43E+03	2.50E+02	5.67E+05
LUIZIANA	2.43E+03	5.81E+02	1.21E+06
LUNARDELLI	2.44E+03	6.06E+01	1.26E+05
LUPIONÓPOLIS	2.44E+03	4.68E+01	9.62E+04
MANOEL RIBAS	2.46E+03	3.24E+02	6.79E+05
MARILÂNDIA DO SUL	2.46E+03	2.81E+02	5.29E+05
MARMELEIRO	2.46E+03	1.71E+02	3.92E+05
MATO RICO	2.46E+03	1.21E+02	2.52E+05
NOVA AMÉRICA DA COLINA	2.46E+03	6.17E+01	1.48E+05
NOVA CANTU	2.46E+03	2.93E+02	6.23E+05
NOVA FÁTIMA	2.47E+03	1.84E+02	4.14E+05
NOVA SANTA BÁRBARA	2.47E+03	6.73E+01	1.55E+05
ORTIGUEIRA	2.48E+03	5.20E+02	1.03E+06
PINHALÃO	2.48E+03	5.09E+01	1.35E+05
PIRAÍ DO SUL	2.48E+03	4.68E+02	7.88E+05
PIRAQUARA	2.49E+03	2.12E+00	4.72E+03
PITANGA	2.50E+03	6.32E+02	1.40E+06
PORTO AMAZONAS	2.50E+03	8.11E+01	1.61E+05
RANCHO ALEGRE	2.50E+03	1.49E+02	3.69E+05
RENASCENÇA	2.50E+03	3.19E+02	6.32E+05
RESERVA	2.52E+03	3.64E+02	7.05E+05
RIBEIRÃO CLARO	2.52E+03	2.25E+01	5.53E+04
RIBEIRÃO DO PINHAL	2.53E+03	1.20E+02	3.07E+05
RIO BOM	2.53E+03	7.25E+01	1.45E+05
RIO BRANCO DO IVAÍ	2.55E+03	5.57E+01	1.17E+05
RIO BRANCO DO SUL	2.55E+03	2.96E+00	4.94E+03

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
ROSÁRIO DO IVAÍ	2.56E+03	1.73E+01	3.85E+04
SALTO DO ITARARÉ	2.56E+03	8.01E+01	1.91E+05
SANTA AMÉLIA	2.56E+03	5.95E+01	1.49E+05
SANTA CECÍLIA DO PAVÃO	2.58E+03	5.82E+01	1.46E+05
SANTA MARIANA	2.59E+03	3.51E+02	7.92E+05
SANTANA DO ITARARÉ	2.61E+03	7.62E+01	1.47E+05
SANTO ANTÔNIO DA PLATINA	2.63E+03	1.49E+02	3.17E+05
SANTO ANTÔNIO DO PARAÍSO	2.64E+03	1.26E+02	2.97E+05
SÃO JERÔNIMO DA SERRA	2.64E+03	2.30E+02	6.05E+05
SÃO JORGE DOESTE	2.66E+03	1.41E+02	3.21E+05
SÃO JOSÉ DA BOA VISTA	2.66E+03	2.30E+02	4.12E+05
SÃO SEBASTIÃO DA AMOREIRA	2.67E+03	1.47E+02	3.27E+05
SAPOPEMA	2.70E+03	3.25E+01	8.97E+04
SENGÉS	2.70E+03	1.80E+02	3.29E+05
SERTANEJA	2.74E+03	3.56E+02	8.09E+05
SIQUEIRA CAMPOS	2.76E+03	3.59E+01	7.62E+04
TELÊMACO BORBA	2.77E+03	6.61E+00	1.23E+04
TOMAZINA	2.78E+03	8.11E+01	1.69E+05
TRÊS BARRAS DO PARANÁ	2.80E+03	2.39E+02	5.04E+05
TURVO	2.82E+03	1.90E+02	4.29E+05
URAÍ	2.82E+03	1.17E+02	2.76E+05
VENTANIA	2.83E+03	2.36E+02	3.94E+05
DOUTOR ULYSSES	2.89E+03	4.68E-01	8.31E+02
VIRMOND	2.93E+03	9.02E+01	1.94E+05
CAÇADOR	2.97E+03	2.63E+01	6.08E+04
CAMPO ERÊ	2.98E+03	2.06E+01	4.57E+04
CURITIBANOS	2.98E+03	1.87E+02	6.15E+05
DIONÍSIO CERQUEIRA	3.01E+03	8.19E+01	1.86E+05
FREI ROGÉRIO	3.01E+03	8.93E+00	2.94E+04
NOVO HORIZONTE	3.07E+03	2.91E+01	8.08E+04
SÃO BERNARDINO	3.19E+03	1.60E+01	3.84E+04
SÃO CRISTÓVÃO DO SUL	3.29E+03	2.81E+00	6.74E+03
SÃO LOURENÇO DO OESTE	3.29E+03	7.49E+01	2.02E+05
PAIM FILHO	3.32E+03	3.07E+01	6.99E+04
SÃO JOSÉ DO OURO	6.45E+03	1.88E+02	4.57E+05

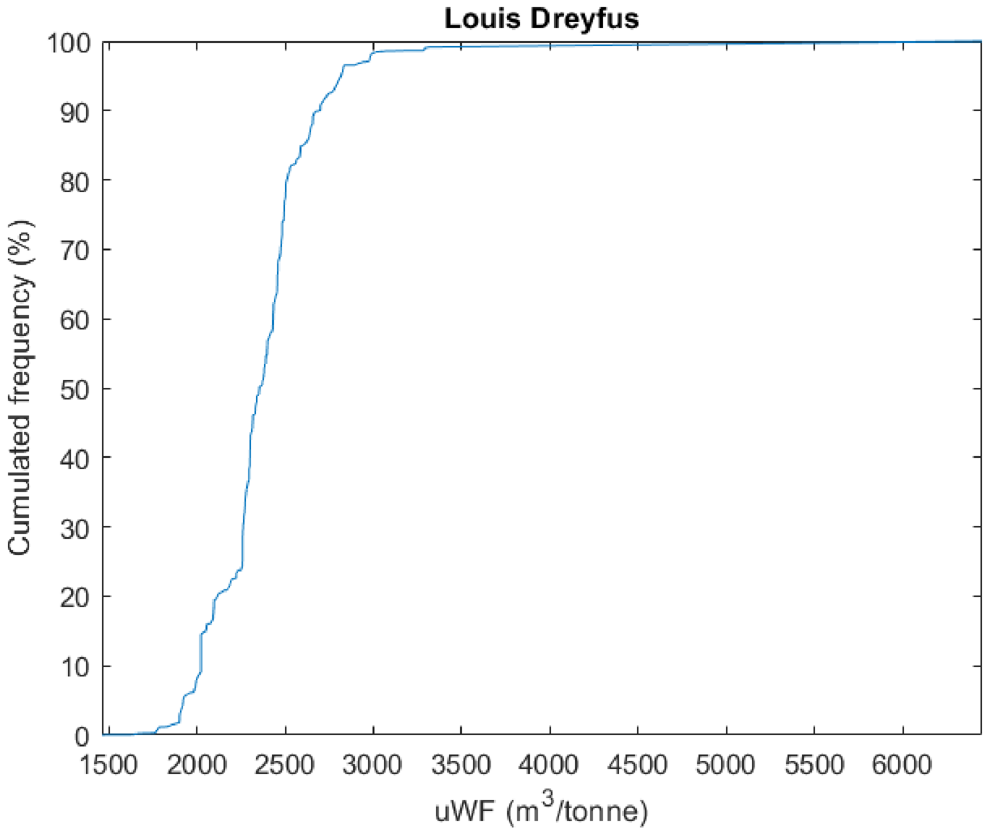

Figure F.0.1: Curve of relative cumulated frequency of uWF $(m^3/tonnes)$ over Louis Dreyfus's sourcing production

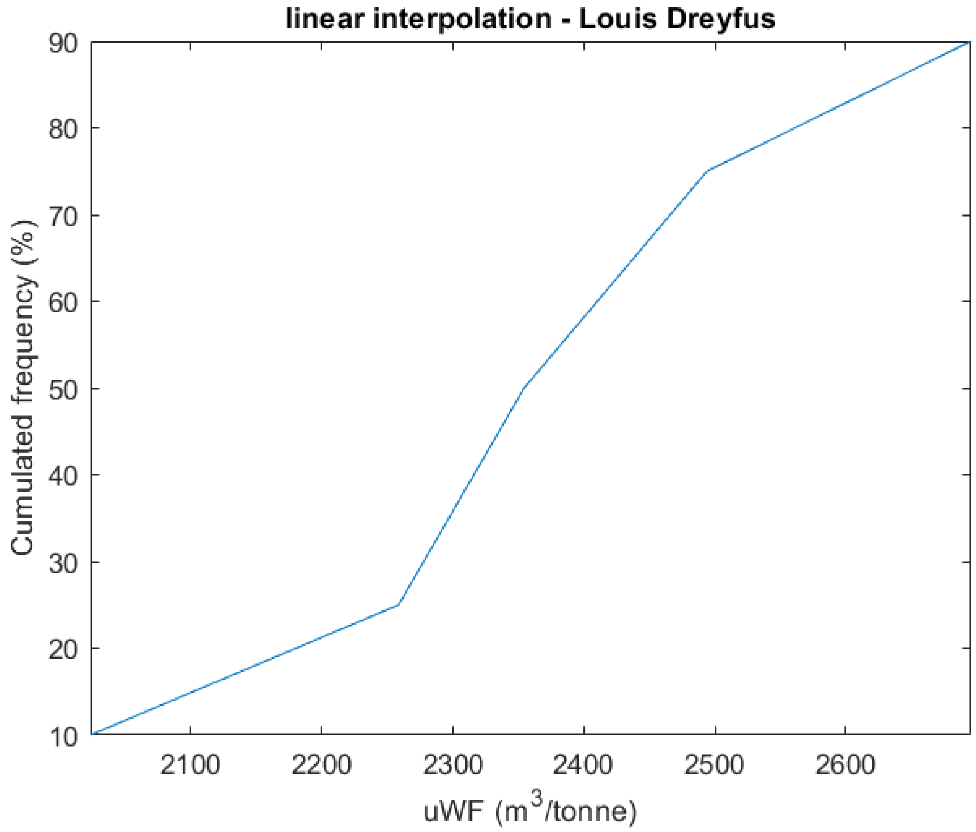

Figure F.0.2: Linearly interpolated curve of relative cumulated frequency of uWF ($m^3/tonnes$) over Louis Dreyfus's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

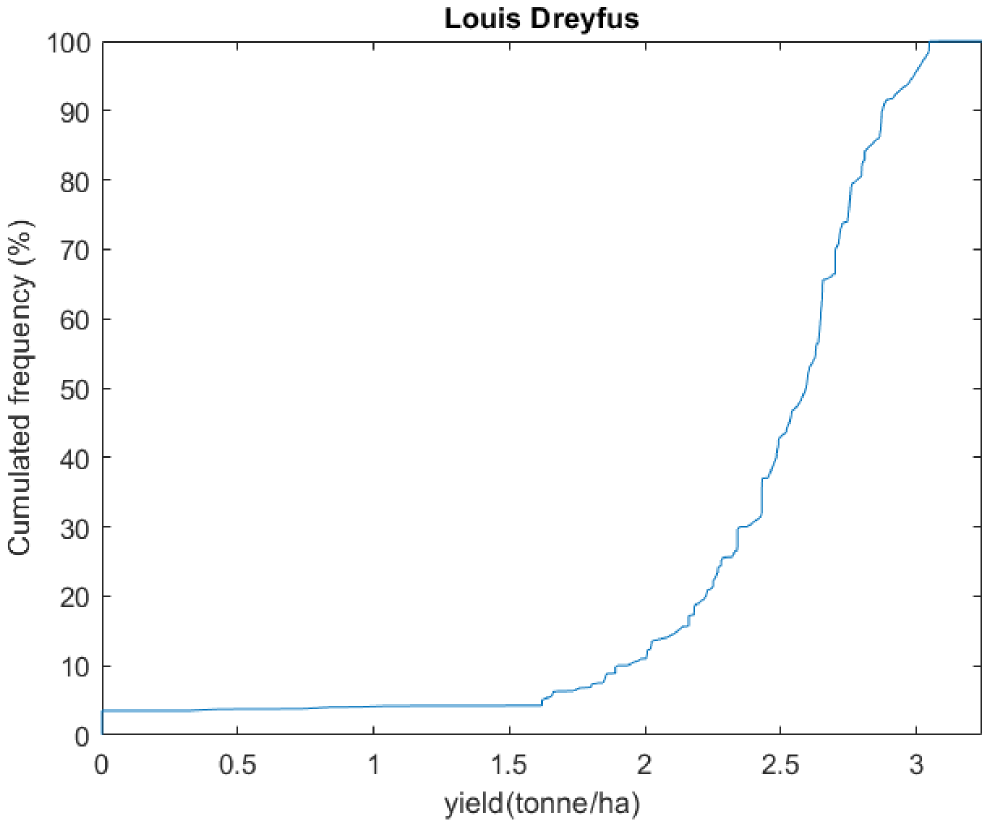

Figure F.0.3: Curve of relative cumulated frequency of yield (*tonnes/ha*) over Louis Dreyfus's sourcing production

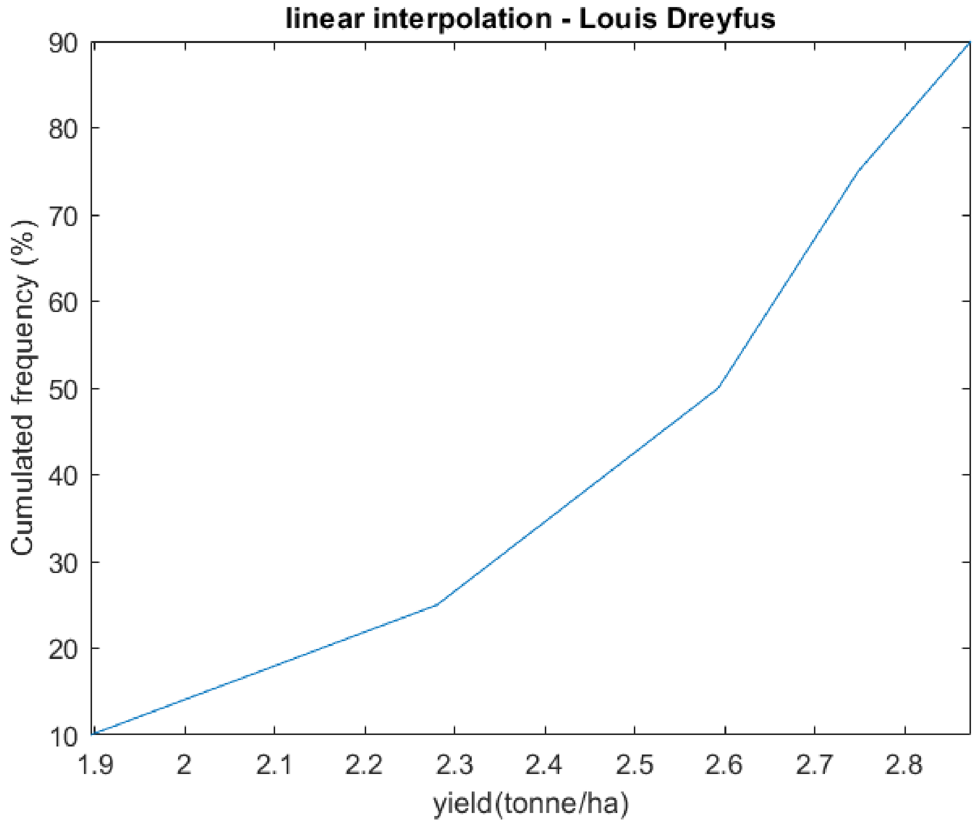

Figure F.0.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Louis Dreyfus's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

Appendix G

Bianchini

Table G.0.1: Bianchini's water footprint volumes toward Italy

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
AGUDO	2.28E+03	1.04E+02	2.92E+05
ALTO ALEGRE	2.31E+03	8.19E+02	2.01E+06
BARRA DO RIBEIRO	2.39E+03	4.76E+02	1.54E+06
BOA VISTA DO INCRA	2.45E+03	1.15E+03	3.03E+06
BUTIÁ	2.52E+03	2.30E+02	8.44E+05
CARAZINHO	2.52E+03	6.21E+03	1.56E+07
CHAPADA	2.54E+03	5.53E+03	1.41E+07
FORTALEZA DOS VALOS	2.63E+03	5.84E+03	1.48E+07
ITACURUBI	2.81E+03	4.42E+02	1.66E+06
JAGUARÃO	2.83E+03	2.75E+03	9.69E+06
MANOEL VIANA	2.92E+03	4.55E+03	1.04E+07
PANTANO GRANDE	2.94E+03	1.73E+03	5.08E+06
QUINZE DE NOVEMBRO	3.00E+03	1.57E+03	3.75E+06
RIO PARDO	3.16E+03	5.72E+03	1.71E+07
SANTA BÁRBARA DO SUL	3.18E+03	1.14E+04	2.62E+07
SANTA MARGARIDA DO SUL	3.24E+03	3.81E+03	1.27E+07
SANTANA DO LIVRAMENTO	3.33E+03	3.29E+03	1.56E+07
SANTIAGO	3.39E+03	7.77E+02	2.47E+06
SANTO AUGUSTO	3.47E+03	5.15E+03	1.46E+07
SÃO JOÃO DO POLÊSINE	3.53E+03	6.04E+01	2.05E+05
SÃO LUIZ GONZAGA	3.67E+03	3.72E+03	1.17E+07

Municipality (-)	**uWF** ($m^3/tonnes$)	**Production** ($tonnes$)	**WF** (m^3)
SÃO VICENTE DO SUL	3.77E+03	9.57E+02	3.33E+06
TUNAS	4.73E+03	6.95E+02	2.03E+06

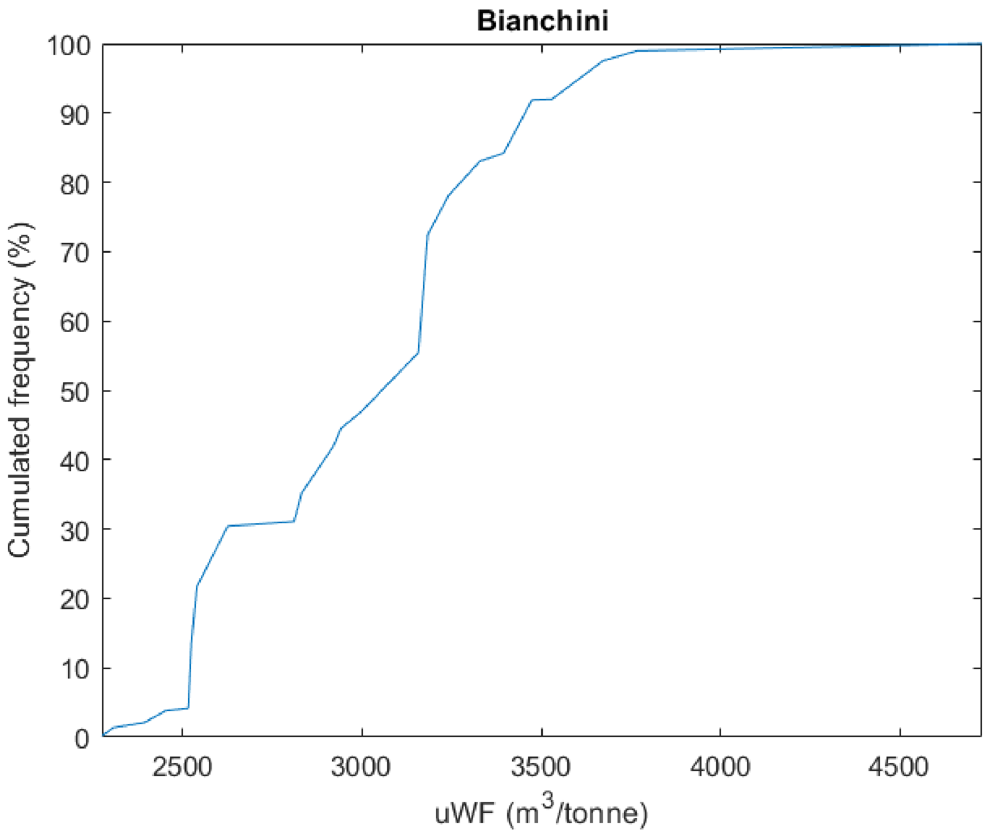

Figure G.0.1: Curve of relative cumulated frequency of uWF ($m^3/tonnes$) over Bianchini's sourcing production

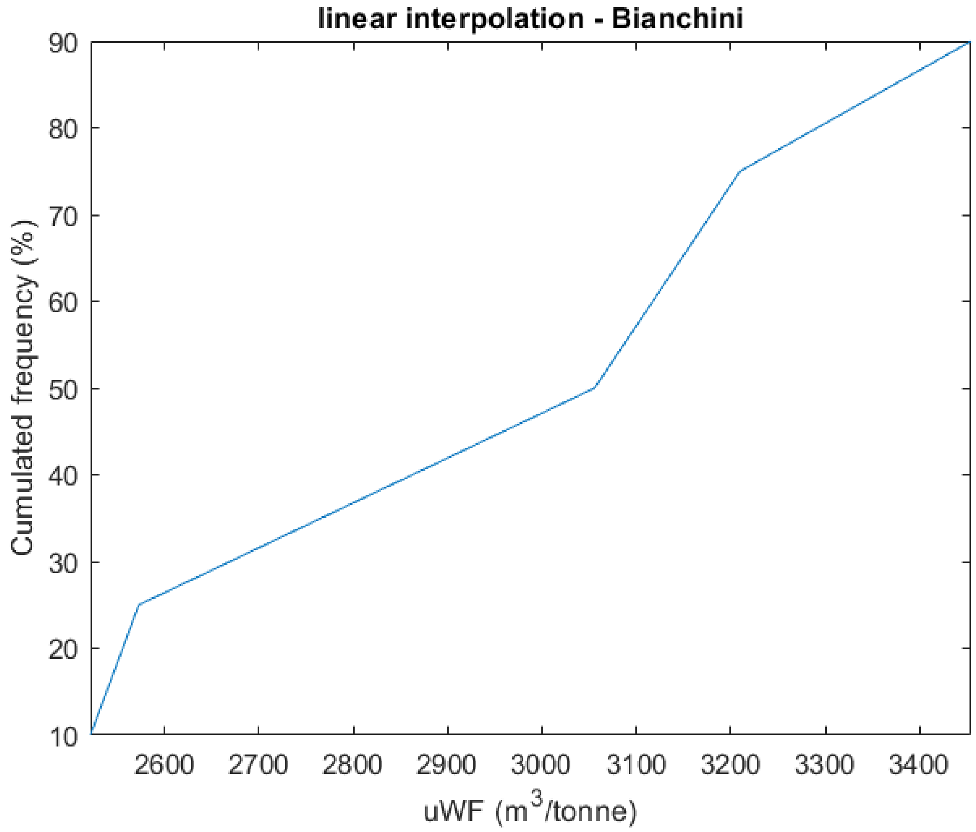

Figure G.0.2: Linearly interpolated curve of relative cumulated frequency of uWF ($m^3/tonnes$) over Bianchini's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

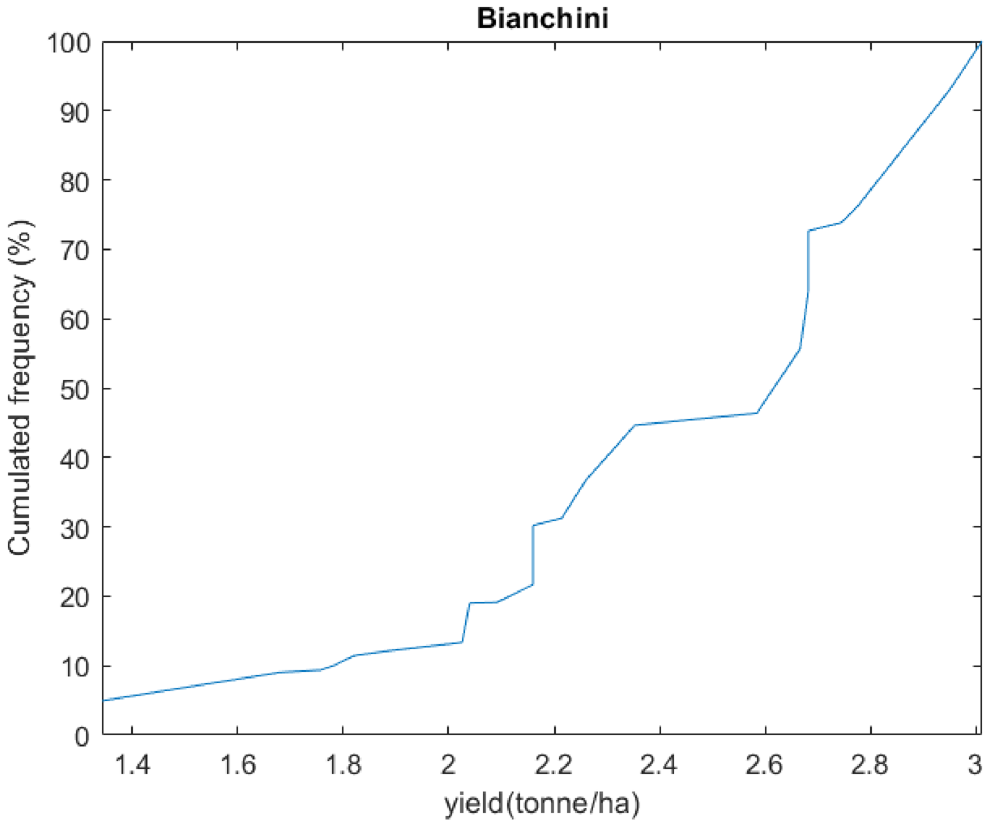

Figure G.0.3: Curve of relative cumulated frequency of yield ($tonnes/ha$) over Bianchini's sourcing production

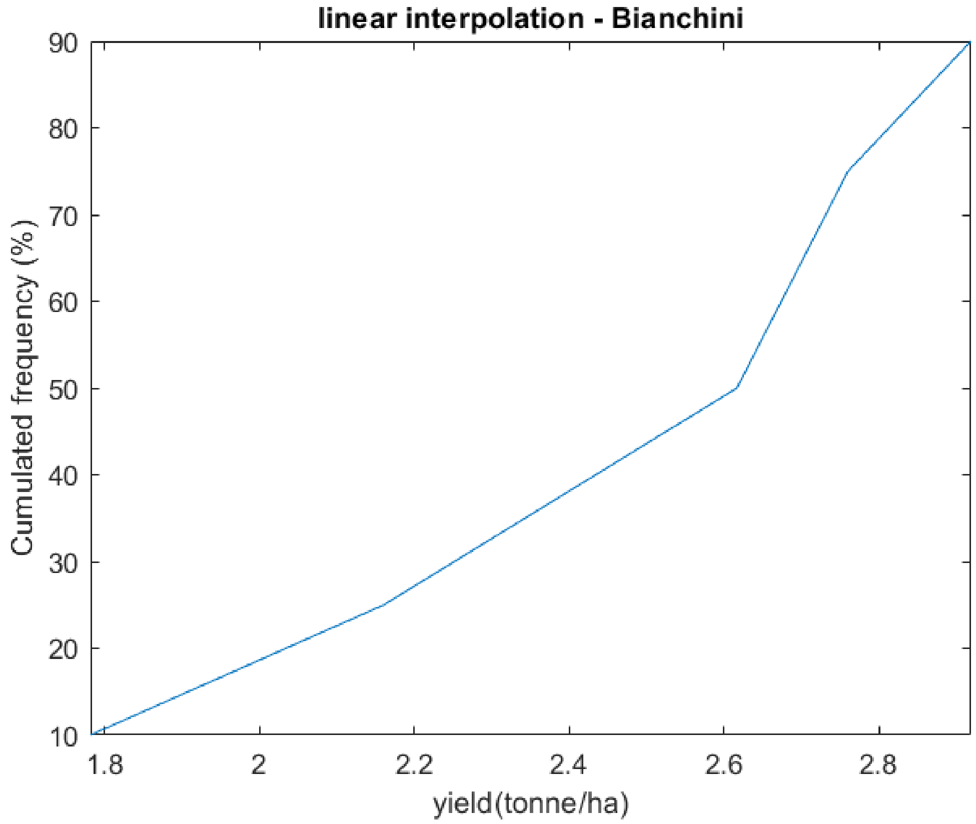

Figure G.0.4: Linearly interpolated curve of relative cumulated frequency of yield ($tonnes/ha$) over Bianchini's sourcing production in the interval between the percentiles of production 10%, 25%, 50%, 75%, 90%

Appendix H

Other European importers

H.1 Spain

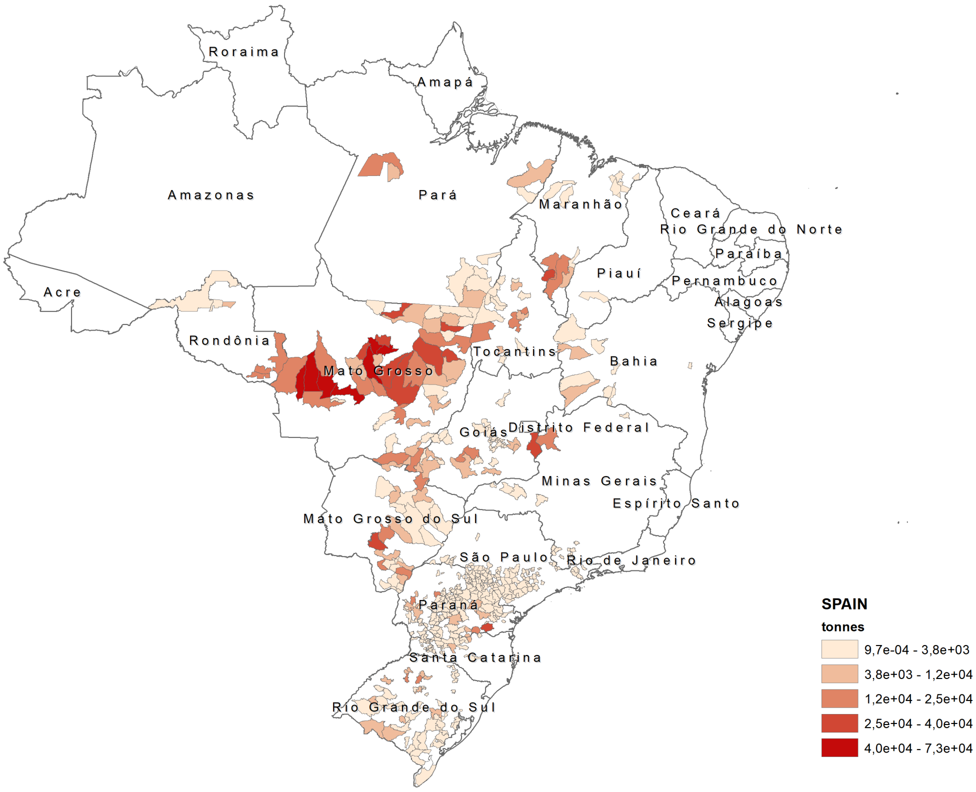

Figure H.1.1: Spain sourcing municipalities for soybean in Brazil, 2018

H.2 Netherlands

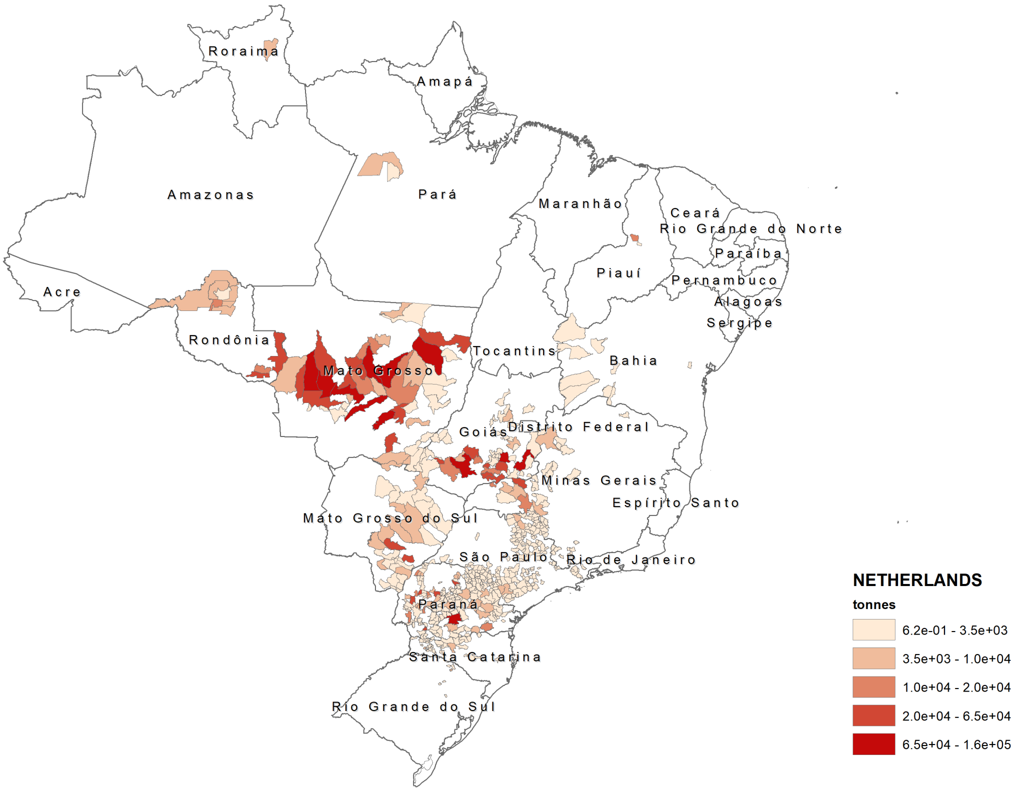

Figure H.2.1: Netherlands sourcing municipalities for soybean in Brazil, 2018

H.3 France

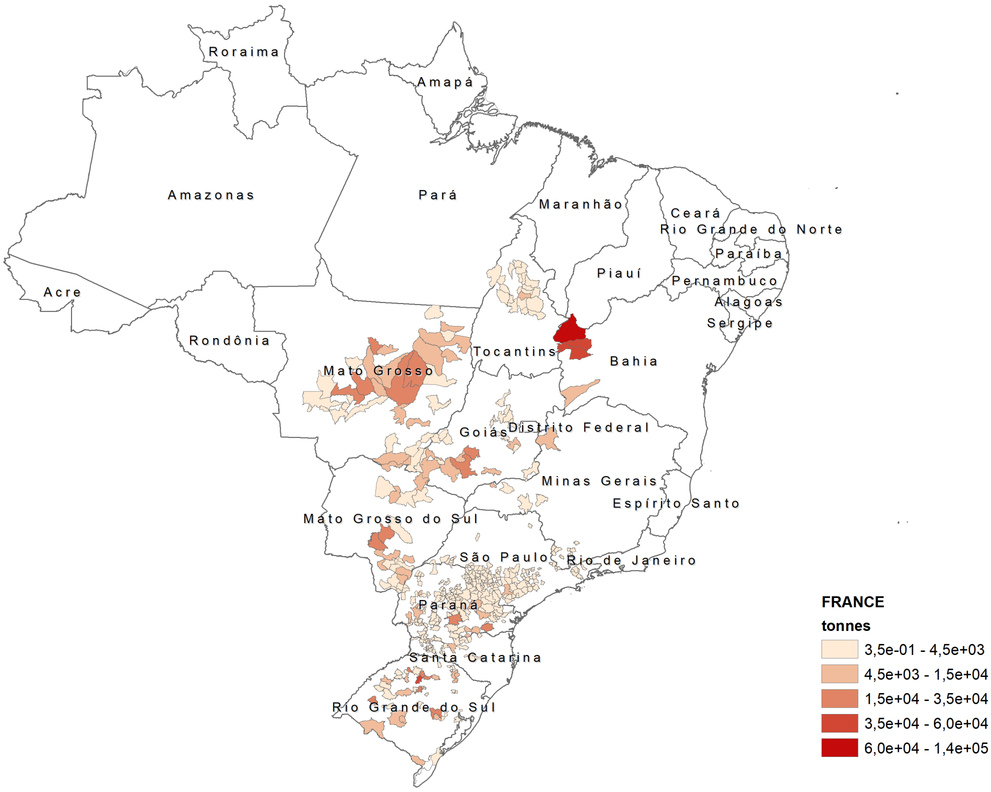

Figure H.3.1: France sourcing municipalities for soybean in Brazil, 2018

H.4 Germany

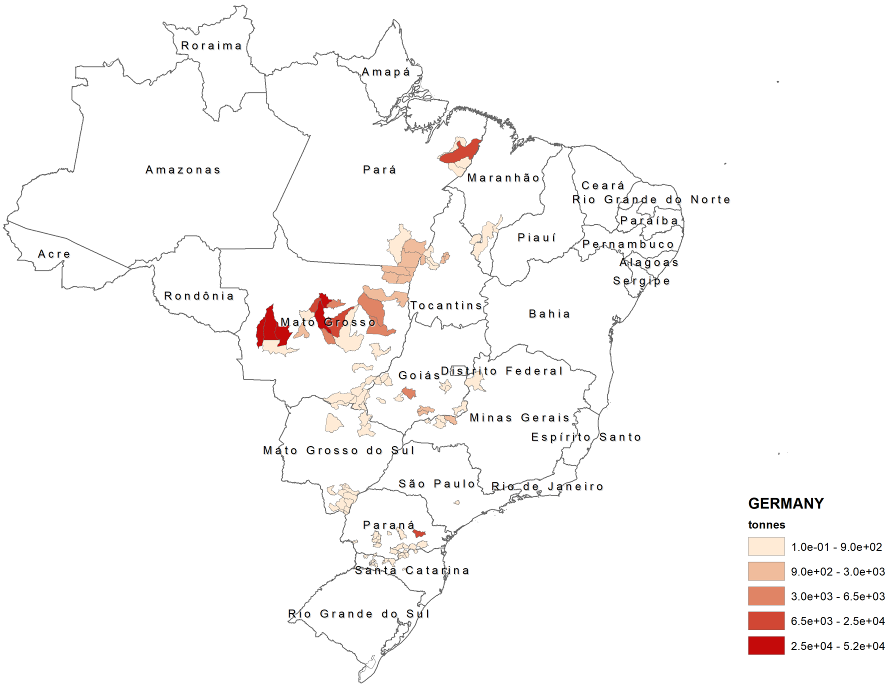

Figure H.4.1: Germany sourcing municipalities for soybean in Brazil, 2018

H.5 United Kingdom

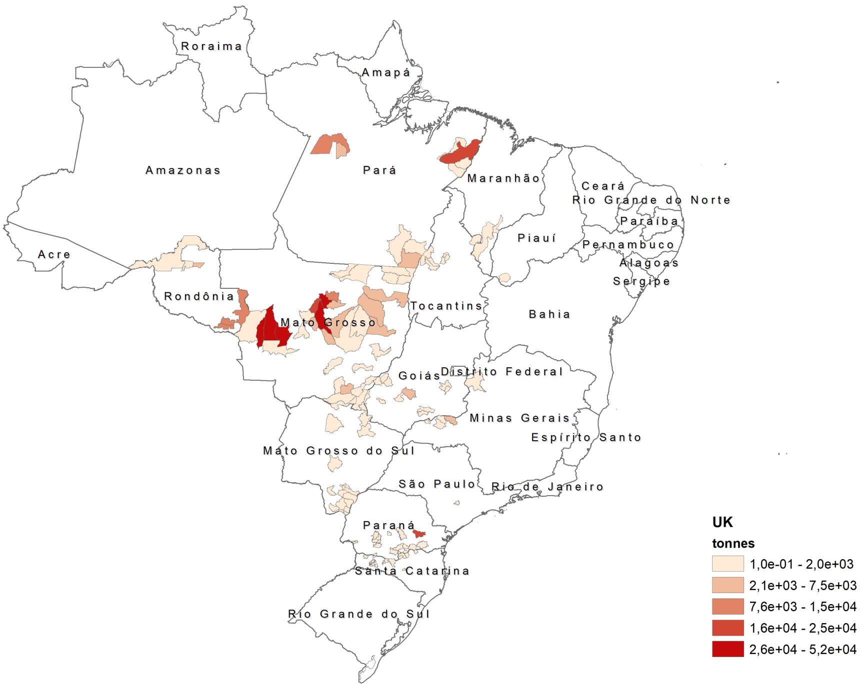

Figure H.5.1: United Kingdom sourcing municipalities for soybean in Brazil, 2018

H.6 Denmark

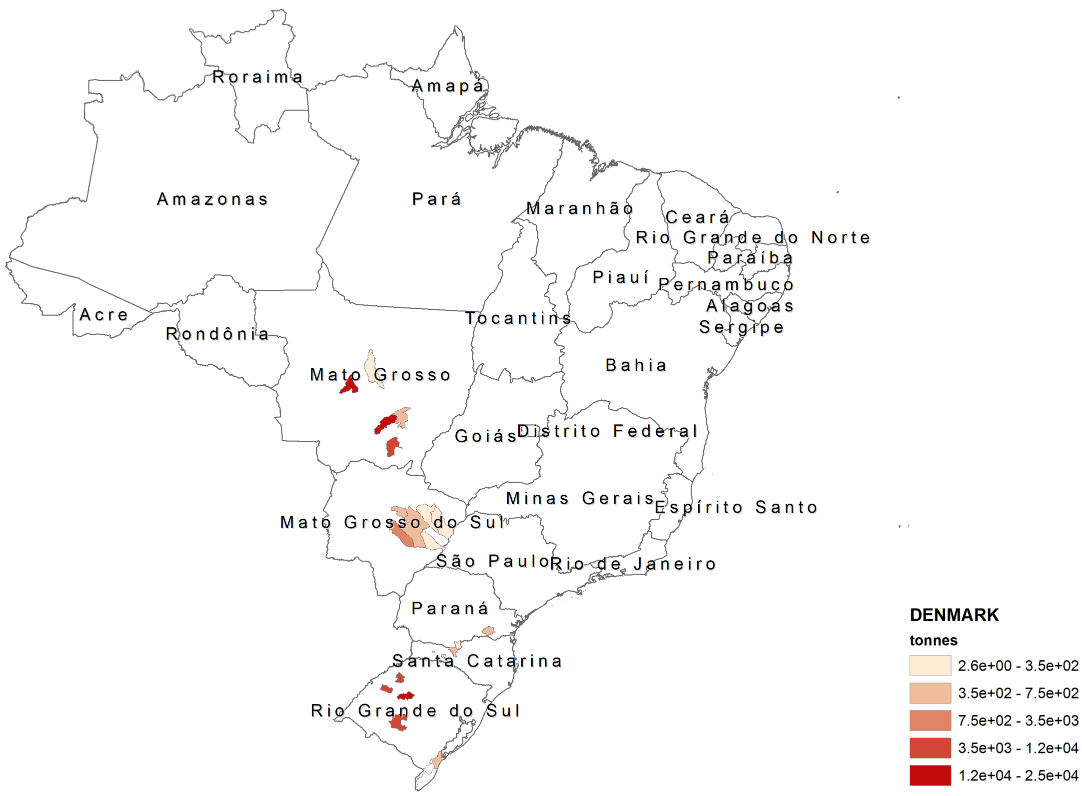

Figure H.6.1: Denmark sourcing municipalities for soybean in Brazil, 2018

H.7 Norway

Figure H.7.1: Norway sourcing municipalities for soybean in Brazil, 2018