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Sustainability Assessment in Soy, Family and Agroforestry Farms: Application of the Rise Tool to the *Cerrado*

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Abstract

Over the last 30 years, extensive areas of *Cerrado*, the Brazilian savannah, have been converted to export-oriented agribusinesses. The social, environmental and economic impact of such large-scale land-use conversion is massive. To understand whether the current farming development in the *Cerrado* is sustainable, this study analyzes the sustainability performance of single farms applying the *triple bottom line* approach. Its aim is to assess the sustainability of soy, family and agroforestry farms. Fifteen farms were analyzed through the indicator-based sustainability assessment tool «RISE». The sustainability scores of RISE themes revealed that soy farms are economically sustainable, while their socio-environmental sustainability degree is rather critical. They scored lower than the other two farm types in all RISE themes except in the «economic viability» and «water use». Family farms and agroforestry are environmentally sustainable according to RISE. The sustainability degree of their social themes is either critical or scarcely positive mainly due to the high number of working hours and the low wage and income level. Looking at the economic sustainability, family farms reached a critical degree and agroforestry farms a barely positive degree. While the difference of sustainability performance between soy farms and the two others is large, it is minimal between agroforestry and family farms. RISE was a valid tool to assess with a moderate amount of data the sustainability performance of highly diverse farm types in the *Cerrado*.

Keywords: Brazil, savannah, comparison, triple bottom line approach, indicator-based assessment.

Valoración de la sostenibilidad en cultivos de soya, cultivos familiares y agroforestales: aplicación de la herramienta RISE en Cerrado

Resumen

En los últimos 30 años, extensas áreas de *Cerrado*, en la sabana brasileña, se han convertido en sistemas agrícolas orientados a la exportación. El impacto social, ambiental y económico que provocaron estos sistemas en el uso de la tierra es masivo. Con el fin de comprender si el desarrollo agrícola actual en *Cerrado* es sostenible, el presente estudio analiza la sostenibilidad de estos sistemas, por medio del enfoque de *triple bottom line*. El objetivo es evaluar la sostenibilidad dentro de tres cultivos agrícolas diferentes: la agricultura de la soya, la familiar y la agroforestal. Para esto, fueron analizadas quince unidades familiares, utilizando una herramienta de evaluación basada en los indicadores «RISE». Los puntajes de sostenibilidad de cada indicador RISE revelaron que los cultivos de soya son económicamente sostenibles, pero su puntaje de sostenibilidad socio ambiental es bastante crítico, alcanzando los puntajes más bajos en todos los indicadores, excepto en «viabilidad económica» y «uso del agua». Los cultivos familiares y la agrosilvicultura son ambientalmente sostenibles, empero, su grado de sostenibilidad social es crítico o escasamente positivo. En cuanto a la sostenibilidad económica, los cultivos familiares alcanzaron un puntaje crítico, mientras que los cultivos agroforestales uno escasamente positivo. Por último, si bien la diferencia de la sostenibilidad, entre los cultivos de soya y los otros dos es grande, llega a ser mínima entre los agroforestales y los familiares. RISE constituyó una herramienta válida para evaluar, con una cantidad moderada de datos, la sostenibilidad de estos tres tipos de cultivos agrícolas en *Cerrado*.

Palabras clave: Brasil, sabana, comparación, triple resultado, evaluación basada en indicadores.

List of Abbreviations

AF	Agroforestry
B	billion
FAO	Food and Agriculture Organization of the United Nations
ha	hectares
MDA	Ministry of Agrarian Development
M	million
PPP	Plant Protection Product
PRONAF	National Program for Strengthening Family Farming
RISE	Response-Inducing Sustainability Evaluation
TBL	*triple bottom line*
USDA	United States Department of Agriculture

I. Introduction

The 2007-2008 global food crisis revealed the instability of the global food system (Clapp & Helleiner, 2012). The crisis pushed millions of people into a situation of food insecurity, thus leading to the eruption of «food riots» in many developing countries. In response, numerous international initiatives were promoted to expand the global food supply and meet the increasing global demand (Clapp & Helleiner, 2012). Notwithstanding the fact that 40% of the grain production goes to livestock farming and that the main problem of the crisis was how food is accessed rather than produced (ETC Group, 2008), the FAO (FAO, 2009) estimated in 2009 that the global food production would have to rise by 70% by 2050 to feed an additional 2.30 billion people. Thanks to increased yields due to advanced production methods in agriculture, the FAO (2009) projected with cautious optimism that the goal could be reached if «only» 120 million ha were additionally cultivated in the savannahs of Sub-Saharan Africa and South America. That optimism may have been partially driven by the massive expansion of crop agribusiness in the *Cerrado* (Rada, 2013), the largest savannah of South America located in central Brazil, south and east of the Amazon (Ratter, Ribeiro, & Bridgewater, 1997).

Vast natural *Cerrado* areas were transformed into extensive pastures for cattle ranching or into farmland for export-oriented crop production (Klink, Oliveira, & Marquis, 2002), in particular into soy farms. Thanks to this unprecedented land-use conversion and the increasing global demand for soybeans, Brazil became the world's biggest soy producer, with 121 M tons per year, and exporter, with 74.9 M tons per year (USDA, 2019). Brazil's «soy supremacy escalation» has been a key element of Brazil's farming modernization process. The modernization, strongly supported by the government since the 1950s, was then driven by the establishment of the agribusiness system. The consolidation of this system in the 1980s forced farming enterprises to adapt and compete in the free international market and created a highly professional and profitable farming environment. New trade deals and cooperative networks allowed cost reductions, and the adoption of the latest farming technologies. The steady increase of productivity, yields and revenues attracted governmental funds, research studies and favorable farming policies. Thanks to the success and long-term stability of the agribusiness system, grain production increased from 50 M to 230 M tons between the 1980 decade and 2017-2018, and cultivated areas from 40 M ha to 62 M ha (Klein & Luna, 2018). As a result of Brazil's farming modernization, the *Cerrado*, a global hot-spot for biodiversity, with 44% endemic vascular plants (Brannstrom, 2008; Myers. Mittermeier, Mittermeier, da Fonseca, & Kent, 2000), was gradually converted into a breadbasket for other places (Rada, 2013).

This large scale change of the landscape lead to numerous environmental trade-offs, including biodiversity loss, deforestation, soil contamination, water shortages and pollution (Carvalho, 1999; Fearnside, 2001), and social trade-offs, such as governance changes, territorial conflicts with traditional land uses (e.g. maroons' settlements) and the alteration of traditional livelihood strategies (Carvalho, 1999; Fearnside, 2001). Additionally, agribusiness farming expansion favored land displacements, thus causing further deforestation of the *Cerrado.* As agribusiness farms purchase neighboring pastures, local cattle farmers move to new land and deforest frontier areas. Hence, agribusiness farming expansion is coupled with cattle ranching re-location and thus indirectly promotes land-use change (Gollnow & Lakes, 2014). To sum up, cattle ranching and agribusiness expansion in the *Cerrado* caused major issues to the local economy, society, as well as the environmental and agrarian structure of the Brazilian savannah (Ferreira Filho & Freitas Vian, 2014).

In response to these environmental and socio-economic changes, well-organized anti-agribusiness movements (e.g. the Landless Farmers Movement) were established and international awareness was raised. Consequently, academic research on the socio-environmental impact of Brazilian farming and, in general, on its sustainability was fostered (Mckay & Nehring, 2014; Richards, 2015; Souza & Chaveiro, 2019). Sustainability can be analyzed with the *triple bottom line* concept («TBL»), which evaluates the financial, social, and environmental performance of organizations. The TBL measures «[…] the impact of an organization's activities on the world […] including both its profitability and shareholder values and its social, human and environmental capital» (Savitz, 2013). Several studies focused on the social and environmental sustainability of farms in the *Cerrado* (Santos, 2005), rather than on their economic sustainability (Rodrigues, Nogueira, & Imbrosi, 2001). Yet, only a few studies fully applied the TBL concept in the *Cerrado* (Cunha, Mueller, Alves, & Silva et al., 1993) and most of them are not available in English. The energy environmental accounting (Rodrigues, Kitamura, Sá, & Vielhauer, 2001) and the life-cycle assessment (Walter, Dolzan, Quilodrán, Oliveira, Silva, Piacente, & Segerstedt, 2011) were the most common study approaches. Some reflected on the farming sustainability at a regional scale (Coutinho, Turetta, Monteiro, Castro, & Pietrafesa, 2017), others on a specific crop (Bonilla, Guarnetti, Almeida, & Gianetti, 2010). Nevertheless, very few of them conducted sustainability investigations at a farm level (e.g. Häni, Braga, Stampfli, Keller, Fischer, & Porsche, 2003; Häni, Stampfli, Tello, & Braga, 2005).

The farm level approach is particularly important because a farm is not only a food, raw material or environmental pollutant source. A farm is firstly an economic enterprise, and a place where people work and live. Hence, the assessment of sustainable farming development in a region or of a crop must not forget to consider the sustainability performance of the single farm. A sustainable farm is an enterprise that individually fulfills the TBL requirements (*i.e.* the economic resilience, social well-being, and environmental integrity) both now and in the long-term (Grenz, 2015).

No single technology, strategy or production system can tackle all of these requirements but rather a diversity of systems depending on specific local requirements (Francis et al., 2003). That is why interdisciplinary indicator-based sustainability assessments are optimal. Although most assessment tools generally give more attention to environmental themes, there are some that entirely cover all three dimensions of the TBL (de Olde, Oudshoorn, Sørensen, Bokkers, & de Boer, 2016). Some tools also integrated a fourth dimension, *i.e.* the political dimension. This is defined by O'Connor (2006) in a tetrahedral model of sustainability as «the 'referee' that arbitrates in relation to the different – and often incompatible – claims made by the actors of the social, [environmental] and economic dimension for themselves and with regard to the other dimensions». It is also referred to as the «governance» dimension of an organization because it consists of conventions, procedures, and institutional arrangements that regulate the behavior and relation of the three TBL dimensions.

As reported by the Sustainable Agriculture Initiative (SAI, 2003), sustainable farming «[...] adopts productive, competitive and efficient production practices, while protecting and improving the natural environmental and the global ecosystem, as well as the socio-economic conditions of local communities». Even though sustainable farming has been strongly pushed by international institutions (*e.g.* the FAO) the meaning of «sustainable» remains a quizzical concept, hard to define and measure (Cirella & Zerbe, 2014). The term «sustainability» varies depending on the users and the context where it is used (Bell & Morse, 2012). It can be roughly categorized into «strong sustainability» and «weak sustainability». The first aims at keeping the natural capital constant and the latter at keeping the sum of natural and human-made capital constant (Daly, 2006). The Brundtland Report defined sustainable development as «development that meets the needs of the present without compromising the ability of future generations to meet their own needs» (UN, 1987). This is particularly relevant in Brazil since farming is one of the main driving forces for development, a development that is mainly pushed by Brazil's historical dualistic «agribusiness - family farming» agrarian structure (Pierri, 2013).

The present study uses the RISE tool to compare the sustainability of agribusiness, family farms, and pioneering agroecological farms according to the TBL concept. Specifically, this study analyzes the sustainability performance of soy farms, family farms, and agroforestry («AF») farms. The first represents the frontrunner of Brazil's agribusiness farming, the second Brazil's traditional farming, the third the most innovative form of agroecological farming. The sustainability performance of each farm was assessed and compared to farms of the same kind. The average RISE sustainability score was calculated for each farm type and then the types were compared with each other.

By applying RISE, a sound and timely indicator-based assessment tool rather novel in the Cerrado, we point out strengths and weaknesses of the individual farm types.

II. Materials and methods

2.1. The study area Cerrado

The *Cerrado* is a savannah ecoregion covering 150 and 220 M ha south and east, respectively, of the Amazon rainforest (Fig. 1). It can be differentiated into four land-cover types which are the *Cerradão* (woodland with trees of 12-15 m high), the *Cerrado sensu strictu* (shrubland with shrubs and small trees of 2-8 m high), the *Campo Cerrado* (grassland), and the riparian forest (Eiten, 1982). The climate of the *Cerrado* is seasonal. The rain season is from October to March and the dry season from April to September. The mean annual precipitation is between 800 and 2000 mm (Ratter et al., 1997) and temperatures are, on average, between 22 °C and 27 °C throughout the year (Klink & Machado, 2005). Soils are acidic and nutrient-poor, mainly oxisoils and ultisoils (according to the USDA, 1999), containing significant concentrations of aluminum. Therefore, soils dedicated to crop agriculture and livestock farming must be fertilized (Ratter et al., 1997) and special modified crops and grasses must be used (Rada, 2013).

Regardless of its poor soil features, the farmland area in the *Cerrado* is increasing dramatically. In 2002, it was estimated to cover 38.9% of the total area (i.e. between 150 and 220 M ha) (MMA, IBAMA, & PNUD, 2009). In 2004, instead, it was estimated to cover around 53% (Machado et al., 2004). The cover of the natural vegetation decreased from approximately 56% in 2002 to 52% in 2008 (MMA et al. 2009). However, Beuchle, Grecchi, Shimabukuro, Seliger, Eva, Sano, & Achard. (2015) estimated a decrease from around 53% in 1990, to 47% in 2010 (Table 1).

Table 1. Farmland area, natural vegetation coverage, and annual net-change rate in the Cerrado from 1990 to 2010 according to different authors

	1990	2000	2002	2004	2008	2010
Farmland area[1]	-	-	38.9% [1]	53% [2]	-	-
Natural vegetation cover	53.10% [3]	49.10% [3]	55.73% [1]	-	51.54% [1]	47.00% [3]
Annual rate of natural vegetation cover net-change	-0.79% [3]	-0.44% [3]	-	-	-	-0.61% [3]

[1]MMA et al. 2009, [2]Conservação Internacional 2004, [3]Beuchle et al. 2015.

2.2. Farm types

Soy farms, family farms, and AF farms were selected as main representatives of agribusiness farming, traditional farming, and agroecological farming, respectively. Soy farms in the *Cerrado* can range from 500 to 10,000 ha. They generally alternate six months of soy cultivation (*i.e.* the main crop) with six months of corn, sorghum or other grain crops cultivation (*i.e.* the secondary crop). Most farms own their machines and hire local dayworkers for planting and harvesting. Soy farms coexist with almost 3.9 M family farms. According to the administrative order MDA No. 111 - 20 November 2003, Brazil's law 11.326 - 24 July 2006 and resolution no. 3.559 - 28 March 2008 «family farms» can be defined so if

1) the size of the establishment or the economic activity in a rural area is at maximum four fiscal modules (the size of the module depends on the municipality),
2) most of the labor used on the farm is sourced from family members,
3) the majority of the income is from farming, and
4) the establishment is managed by the family.

Family farm features strongly differ from those of agribusinesses. Typically, family farms are unable to modernize and incorporate new technologies, and do not have access to global markets. Therefore, they adopt different business models and economic risk trajectories than agribusinesses. In practical terms, they usually cultivate a more diversified portfolio of food products (Ferreira Filho & Vian, 2014). They represent 77% of all farming establishments but occupy only 25% of the total Cerrado's farmland area (i.e. 80.9 M ha). However, family farms produce 70% of all food consumed in Brazil (IBGE, 2017).

Family farming and agribusiness farming serve different purposes and are supported by their independent institutions, *i.e.* the Ministry of Agrarian Development (MDA) for agribusinesses, and the National Program for Strengthening Family Farming (PRONAF) for family farms. Over the years, the two institutions have increased political space and agricultural funds to the farm categories they represent (Mckay & Nehring, 2014). That is why the «agribusiness - family farming» agrarian structure and its representative institutions are commonly referred to as Brazilian farming «dualism» (Pierri, 2013). Yet, the dialogue and collaboration among the two farming institutions and their agendas have always been conflictual or nonexistent, reflecting the tension or indifference between the two farming systems (Zanella & Milhorance, 2016).

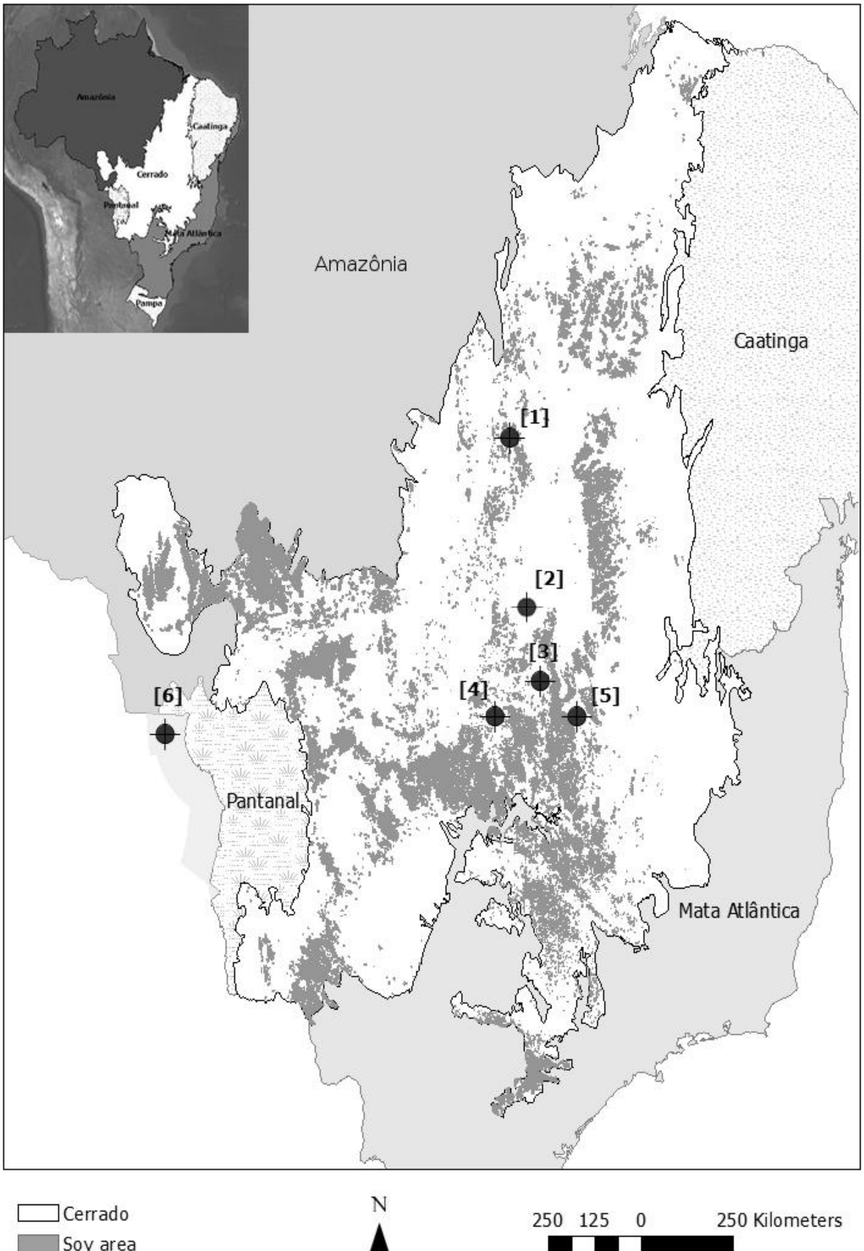
Agroforestry is part of agroecology, a science and set of farming practices that combines agronomy, society and ecology. Its goal is to create biodiverse, resilient and fertile environments, use and recycle the nutrients and the energy of agroecosystems, while maintaining their self-sustaining capacity. Agroecological farming strives to achieve diversification at farm and/or landscape level, augment biological interactions and agroecosystem synergies as well as reduce dependence on agrochemicals and energy inputs (Altieri 2002; Nicholls, Altieri, & Vazquez, 2017). Agroforestry is defined as «a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence» (FAO, 2015). Its specific goal is to optimize land use, integrate food and energy production with forest ecosystem services, reduce land pressure and preserve soil through agroecological farming practices (Duboc, 2008). According to Schuler (2018), the Cerrado contains only 4% of all Brazilian AF systems (49% are in the Mata Atlantica ecoregion, 29% in the Amazon and 19% in the Caatinga). Some of the Cerrado AF farms that we interviewed were consistent with the definition of «family farm», some others were not. That is why we decided to classify AF and family farms as two distinguished farm types.

2.3. Interviews on the farms and the RISE approach

Fourteen farm managers representing the three farm types were interviewed with semi-structured interviews (Fig. 1). The interviews were completed by observations made during the farm visit. In case the farm could not be visited, the farmer's answers were double-checked with photos of the farm or through the assistance of the partner association RURALTINS. One additional soy farm in the Bolivian department of Santa Cruz de la Sierra, 100 km away from the Brazilian border, was included in the study. Even though it was not located within the study area its features were comparable to the ones of soy farms in the Cerrado.

In order to process the 15 RISE assessments, the interview findings were checked for plausibility and added to the RISE software. Some of the RISE evaluation functions (reference values) were regionally adjusted to better fit the features of the farms in the five *Cerrado* municipalities. Fourteen farms were included in the *Cerrado Goiano* RISE region and one to the *Cochabamba* RISE region. We also used Google Earth (satellite images taken in 2019) to extract additional environmental information, research studies to check the plausibility of farmers' answers, and official online databases to derive specific information (e.g. the active ingredient of Plant Protection Products –«PPPs»– that the farmers referred to with their commercial name). All farmers' interviews were conducted in Portuguese without the help of an official translator. Partially erroneous translations may have resulted in misleading interview findings and communication misunderstandings may have affected our research. Some farms did not deliver all the data required to undergo a full RISE assessment, so some themes were not or only partially evaluated. This implies that some indicators of that theme were complete,

Figure 1. Soy area in the Cerrado and location of the six farm municipalities: [1] Porto Nacional (six family farms and two soy farms); [2] Alto Paraiso de Goiás (two AF farms); [3] Brasilia; (one AF farm); [4] Goiânia (one family farm and one AF farm); [5] Unai (one AF farm); [6] Santa Cruz de la Sierra (one soy farm).



others were not, and could not be considered in the calculation. Nevertheless, we were able to assess all 15 farms, and obtain 15 complete or partial sustainability polygons. Single farm assessments were then grouped by farm type (*i.e.* AF, family and soy farm) and an average score was computed. The three average scores of AF farms, family farms, and soy farms were then plotted and compared on a sustainability polygon (Fig. 2). After the first comparison analysis, farms were then grouped into two categories, *i.e.* firstly, agroecological farms, family and soy farms, and secondly, agribusiness and smallholder farms. Again, results were plotted and compared on a sustainability polygon (Fig. 2).

We expected RISE results to provide a deep insight of the sustainability, as expressed by the TBL, of every farm type, both small- and large-scale. RISE results could not be discussed with the farm managers because communication with them either could not be re-established after the interview and/or farm visit or was too unproductive to discuss farming details via e-mail. On a practical note, this would have permitted us to double-check our results and start an advisory process to support the farm in its sustainable development. Nonetheless, results allowed us to give general recommendations to improve the sustainability of each farm type.

III. Results

We were able to assess nine of ten RISE sustainability themes for family and agroforestry farms. The «animal husbandry» theme did not apply to our assessment, since the focus was on crop production, and only one AF and some family farmers had livestock. We were able to assess eight of ten themes for soy farms. Besides «animal husbandry», also the «quality of life» theme could not be calculated. Due to time constraints, we could not answer all the questions about the «quality of life» of soy farmers. This impeded RISE to calculate a sustainability score for that theme.

Results revealed that the environmental and social sustainability degrees of AF and family farms are clearly greater than the ones of soy farms. Also, soy farms have a smaller governance sustainability degree but a clearly greater economic sustainability degree. Furthermore, the sustainability polygons of AF and family farms are surprisingly similar (Fig. 2). As shown in Table 2, four of five environmental themes of Brazilian family farms are at a positive sustainability degree. Nevertheless, the «energy and climate» theme falls by a hair into the critical degree. Among the 23 environmental indicators, «ecological infrastructure» and «soil compaction» registered the highest scores (*i.e.* 100 and 96, respectively), while «soil reaction» and «energy intensity of agricultural production» had the lowest (*i.e.* 50 and 53, respectively). With respect to social sustainability, the «quality of life» theme obtained a positive sustainability degree, especially thanks to the score of the «social relations» indicator (*i.e.* 88). However, the social theme «working conditions» obtained a critical sustainability degree, mainly due to the low score of the «wage and income» indicator (*i.e.* 20). Concerning economic sustainability, the «economic viability» theme is at a critical degree. It is strongly affected by the low score of the «profitability» indicator (*i.e.* 43) and the high score of the «livelihood security» indicator (*i.e.* 79). Finally, the good governance dimension, consisting of the «farm management» theme and «business goals, strategy, implementation», «availability of information», «risk management» and «resilient relationships» indicators, shows that family farms are at a positive sustainability degree. This resulted from the high scores of the «risk management» and «resilient relations» indicators (*i.e.* 97 and 90).

In a similar way to family farms, four of five environmental themes of AF farms have a positive sustainability degree. Once again, the «energy & climate» theme is at a critical degree. In this case, however, the difference with family farms is evident because the score is clearly lower (*i.e.* 48 compared to 65). Of the 23 environmental indicators, «energy intensity of agricultural production» and «energy management – part of the «energy & climate» theme - registered the lowest scores (*i.e.* 24 and 45). In contrast, the «ecological infrastructure» and «soil compaction» indicators registered the highest scores (*i.e.* 100 and 98). With respect to social sustainability, the similarity of AF farms to family farms is clear. The score of AF farms' «working conditions» theme is greater than the one of family farms, but still falls into the critical sustainability degree. This is because of the low score obtained by the «personnel management» indicator (*i.e.* 43) and the high score obtained by the «safety at work» indicator (*i.e.* 92). The «quality of life» theme, instead, falls into the positive sustainability degree, especially thanks to the high score of the «social relations» indicator (*i.e.* 82). Concerning economic sustainability, AF farms are more economically viable than family farms: by an extremely narrow margin, their score falls into the positive sustainability degree. That is because they are more profitable (*i.e.* «profitability» score is 60 instead of 43) and have less debts (*i.e.* «indebtedness» score is 80 instead of 64). Nevertheless, their liquidity is much smaller (*i.e.* «liquidity» score is 24 instead of 60), meaning that they can live on their cash reserves for a shorter time than family farmers can. Finally, the good governance dimension shows that AF farms are at a positive sustainability degree. This resulted from the high scores of the «risk management» and «resilient relations» indicators (*i.e.* 100 and 94).

The average sustainability polygon of soy farms has a completely different shape than the one of AF and family farms. Of the 23 environmental indicators, «biodiversity management» and «distribution of ecological infrastructure» registered the lowest scores (*i.e.* 0 and 3). In the social dimension, only the «working conditions» theme falls into the critical sustainability degree, reaching scores that are, however, remarkably lower than those of AF and family farms. This is due to the smaller scores obtained by the «working hours» and «safety at work» indicators (*i.e.* 32 and 76). Concerning the economic dimension, soy farms are highly sustainable and clearly exceed the two other farm types. This is thanks to the peak scores of the «liquidity», «profitability» and «indebtedness» indicators (*i.e.* 100, 100, 98). Nevertheless, the «stability» indicator registered a smaller score than the other two farm types (*i.e.* 65 instead of 74 and 81). Also, the good governance dimension has a lower score and falls into the critical sustainability degree. This is due to the lower scores reached by the «business goals, strategy, implementation» and «risk management» indicators (*i.e.* 64 instead of 88 and 89; 67 instead of 100 and 97).

Table 2. Theme scores (in bold typeface) and indicator scores (in Roman typeface) of an average AF, family, and soy farm, according to the RISE approach.

	AF farm	Family farm	Soy farm
1. Soil use	77	79	58
1.1 Soil management	90	91	83
1.2 Crop productivity	60	63	38
1.3 Soil organic matter	71	82	83
1.4 Soil reaction	53	50	46
1.5 Soil erosion	90	93	100
1.6 Soil compaction	98	96	0
2. Animal husbandry	-	-	-
2.1 Herd management	-	-	-
2.2 Livestock productivity	-	-	-
2.3 Opportunity for species-appropriate behavior	-	-	-
2.4 Living conditions	-	-	-
2.5 Animal health	-	-	-
3. Materials use & environmental protection	74	82	48
3.1 Material flows	-	-	-
3.2 Fertilization	-	-	-
3.3 Plant protection	-	-	-
3.4 Air pollution	-	-	-
3.5 Soil and water pollution	-	-	-
4. Water use	73	72	76
4.1 Water management	61	75	49
4.2 Water supply	67	60	90
4.3 Water use intensity	70	74	89
4.4 Irrigation	-	-	-

	AF farm	**Family farm**	**Soy farm**
5. Energy & Climate	48	65	46
5.1 Energy management	45	61	39
5.2 Energy intensity of agricultural production	24	53	99
5.3 Greenhouse gas balance	77	80	0
6. Biodiversity	79	75	28
6.1 Biodiversity management	80	87	0
6.2 Ecological infrastructures	100	100	87
6.3 Distribution of ecological infrastructures	65	58	3
6.4 Intensity of agricultural production	82	71	42
6.5 Diversity of agricultural production	65	60	10
7. Working conditions	62	55	44
7.1 Personnel management	43	62	35
7.2 Working hours	64	45	32
7.3 Safety at work	92	93	76
7.4 Wage and income level	44	20	33
8. Quality of life	73	78	-
8.1 Occupation & Training	75	79	-
8.2 Financial situation	71	78	-
8.3 Social relations	82	88	-
8.4 Personal freedom & values	46	59	-
8.5 Health	75	72	-
8.6 Other areas of life	-	-	-
9. Economic viability	67	64	88
9.1 Liquidity	29	60	100
9.2 Profitability	60	43	100
9.3 Stability	81	74	65
9.4 Indebtedness	80	64	98
9.5 Livelihood security	83	79	67
10. Farm management	84	90	64
10.1 Business goals, strategy, implementation	88	89	64
10.2 Availability of information	56	79	59
10.3 Risk management	100	97	67
10.4 Resilient relationships	94	90	84

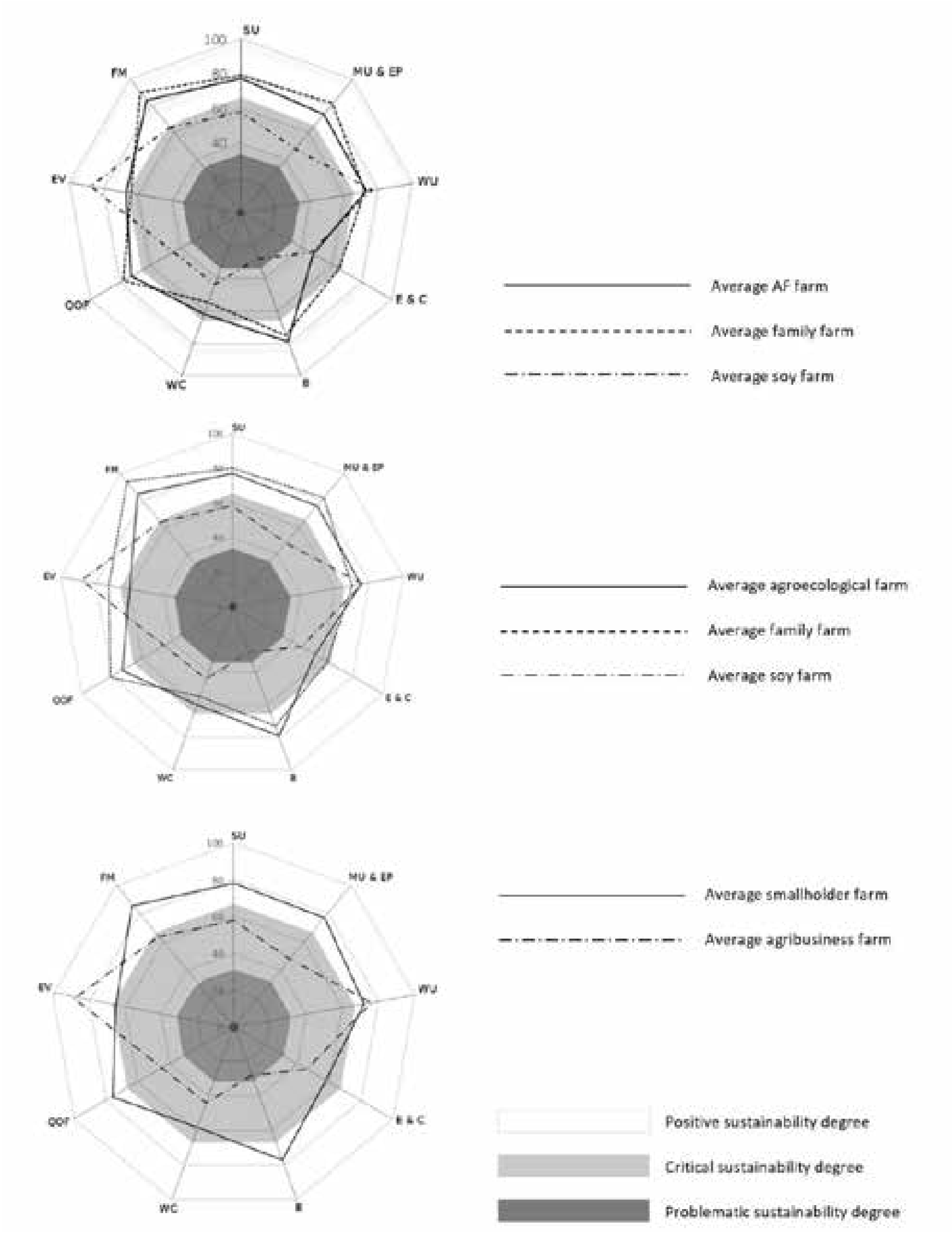
3.1. Comparison of the average agroecological, family, and soy farm

To understand the surprising similarity between the sustainability polygons of the average AF and family farms, a different method to classify farms was used. That is, three family farms that used organic and agroecological farming practices were added to the AF farm group. Although the farm layout of AF and family farms was remarkably different, meaning that they ought to be classified in separate groups, some farming practices were performed by both farm types. This common feature allowed us to attempt a reclassification. The average sustainability scores of this new farm type was then calculated, and the outcome was called «average agroecological farm» (Fig. 2). The comparison between the average agroecological, family, and soy farm, revealed that agroecological and family farm polygons have a similar shape, while the shape of the soy farm polygon is quite different. The similarity between the average agroecological and family farm resembles the previous similarity between the AF and family farm, but with some differences on the «energy & climate» and «economic viability» themes. This different classification reduced the gap between the continuous and dashed line on the «energy & climate» theme, while it inverted them on the «economic viability» theme. In other words, agroecological and family farms have a more similar «energy & climate" critical sustainability degree than AF and family farms. Also, family farms are more economically viable than agroecological farms, while AF farms were previously more viable than family farms. What is more, family farms now have a positive sustainability degree, whereas agroecological farms have a critical degree.

3.2. Comparison of the average agribusiness and smallholder farm

As the difference between AF farms and agroecological/family farms was still small, a third sustainability polygon comparison was elaborated. In this last, we compared the average sustainability polygon of soy farms, representing large-scale agribusinesses, and non-soy farms, representing smallholder farms in the *Cerrado* (Fig. 2). The outcome revealed a significant difference between the two polygons. Smallholder farms largely surpass large-scale agribusinesses in all sustainability themes, except for the «economic viability» theme. They have a positive sustainability degree in six themes and a critical sustainability degree in three themes (*i.e.* «economic viability», «energy & climate» and «working conditions»). Conversely, large-scale agribusinesses have a critical sustainability degree in seven themes, a positive degree in one theme (*i.e.* «economic viability») and a problematic degree in one theme (*i.e.* «biodiversity»).

Figure 2. Sustainability polygons comparing the sustainability performance of an average 1) AF, family and soy farm, 2) agroecological, family, and soy farm, and 3) agribusiness and smallholder farm, in the following RISE themes: soil use (SU), material use & environmental protection (MU & EP), water use (WU), energy & climate (E & C), biodiversity (B), working conditions (WC), quality of life (QOF), economic viability (EV) and farm management (FM).



IV. Discussion

Although our sample may be too small to claim that the sustainability performance of most soy, family and agroforestry farms in the *Cerrado* is as the one of our average farms, our results can be used in relation to the current literature on the sustainability of these three farm types. According to Fernandes and Woodhouse (2008), Brazilian ecological family farms have a slight higher environmental sustainability degree than non-ecological farms. According to our results, instead, family farms in the *Cerrado* are overall environmentally sustainable regardless of their (non) use of fertilizers and/or PPPs. However, they have room for improvement at energy level, especially with regards to energy intensity and management. The energy intensity score may have been affected by the fact that some family farms transformed raw materials into other products (e.g. dairies, vegetable sauces, marmalades). Such artisanal or industrial transformations require additional energy. None of the soy farms transformed their soybeans into other products. Soybeans are sold to another company in charge of exporting or processing them. Even though the quality of life on a family farm is high, working condition improvements are also necessary. The wage of workers and employees is extremely low, and working hours are too many. Nonetheless, safety in the workplace is in order. Although some family farms used toxic pesticides, registered accidents were rare and child welfare was respected.

Family farms are not, or only partially, economically viable and depend on credits from state funding programs, like the PRONAF. Even then, their liquidity and profitability levels are critical. In fact, the PRONAF fund does not improve the financial incomes of family farmers but rather their productive capacity, meaning that it enables them to make investments, increase their farmland area or farming efficiency. This may have positive, ambivalent or negative effects on the farm or the family, but it cannot increase the liquidity or profitability level (Guanziroli, 2007). Still, the livelihood security level of family farmers is greater than that of soy farms and they are not affected by major threats. They have a better risk management thanks to their more diverse production and cooperation with other family farms. Such outcomes are in line with the hypothesis that family farmers have built livelihood diversification strategies and found ways to resist the increase of social vulnerability caused by agribusiness expansion (Schneider & Niederle, 2010). Family farm managers are strongly committed to their definition of «good farm» and the farm's mission, which is to work the land in a «good way», to generate employment and sustain the family. They do not have a clearly defined relationship with the natural environment but rather a general respect for it.

AF farms in the *Cerrado* are as environmentally sustainable as family farms, despite their agroecology-focused mission and business management. In fact, their score on the «energy & climate» theme is clearly lower than the one of family farms. Their energy consumption for agricultural production is rather high and poorly monitored. Perhaps, this is because three of five interviewed AF farms were at their initial development stage, being less than two years old. Not much is known about AF farms' energy consumptions. However, at their initial stage, the establishment and implementation costs are the major challenge in terms of both expenditures and working hours (Tremblay, Lucotte, Revéret, Davidson, Mertens, Passos, & Romaña, 2015). These costs put the AF farmer's management skills highly under pressure and may affect the AF farmers' capacity of handling energy consumption properly. As argued by McGinty, Swisher, & Alavalapati (2008), a key factor for the development of an AF farm is the farmers' self-perception of having the capacities and the knowledge needed to establish and maintain the AF system properly. At the initial stage, such perception may be compromised by the lack of a solid farming heritage. Something that family farmers, on the contrary, have. The working conditions on an AF farm are better than on a family farm but remain critical. Personnel is employed through incomplete contracts, and the wage of workers is too low. Nevertheless, it is higher than the wage of soy and family farm workers, and the number of working hours is less. From a socio-environmental point of view, our results agree with Götz, Harvey and Vincent (2004), that AF can be considered as a natural resource management strategy capable of reconciling agricultural development with the conservation of soil, water, regional climate, and biodiversity.

The assessed AF farms are barely economically viable. Their liquidity is too low, but they do not depend on state funds and are more profitable than family farms. This supports the idea of Toniolo and Uhl (1995) that intensive forms of agriculture have a higher profitability and productivity. In particular, AF are economically more advantageous because of crop diversification and multiple income sources, which represent a major stability factor (Malézieux, 2012). In disagreement with Ewel (1986), the low yields of nature-like ecosystems such as AF farms is not a limitation to the farm business and does not compromise their profitability. In fact, an interviewed AF farm that cultivates wheat reached a productivity comparable to the one of agribusiness farms (*i.e.* 2 t per ha). In addition, the development of the full revenue potential of AF farms takes several years. The AF farm manager of a 1-year-old farm claimed that «the goal [of the farm] is to become economically sustainable as other long-established AF farms. In the next years, we will have sufficient income from agricultural production to properly pay all employees. Then, we will organize AF training courses to have additional income sources». Finally, AF farms score high on the «farm management» theme. The score value is slightly lower compared to the one of family farms because of the «availability of information» indicator. AF farm managers lack information about water and soil quality that family farm managers have, since they receive environmental consultancy from *RURALTINS*. Furthermore, AF farmers' definitions of «good farm» and mission of the farm are deeply connected to agroecological principles and go beyond the meaning of «sustainability». Two AF farmers declared that «Sustainable is outdated. Regenerative is better», meaning that farming to sustain the needs of today's and future generations is not enough for them. A farm must be «more-than-sustainable», meaning that it must generate additional capital for them, the *Cerrado*, the community, and the future generations. This reflects their way of financially managing their farm. That is by accepting their current low liquidity level and by making investments to have higher liquidity and profitability levels in the future. In general, their average belief is that a «good farm» should be a healthy workplace that combines food production with the conservation of the environment and the restoration of the *Cerrado*. Their mission is consistent with the concept that ecosystem restoration is a tool for practicing «strong sustainability» (Zerbe, 2019). Also, their mission is not restricted to the farm's boundaries. In line with Tremblay et al. (2015), AF farmers strive to and can become farming models and agents of change in their communities. By providing successful examples, they attempt to convince people that AF is the key solution to oppose agri-business farming. One farmer stated in the interview that «in two years from now, we will have the organic certification and our business will become economically sustainable. In five years from now, the property will be entirely covered by AF systems and integrated with dairy farming [...]. We will also start natural educational courses for women and children on farms, and we will establish a cooperative for cultivating and selling products of the *Cerrado* [...]». Embracing a humanitarian spirit, they seek to help more people establish an AF farm in their home region and change their urbanized lifestyle into a closer-to-nature lifestyle.

The difference between AF and family farms can be explained by looking at the «energy & climate» theme - as family farms consume less energy for agricultural production and monitor consumptions better than AF farms do – and the «economic viability» theme – as they are not as economically viable as AF farms are. The continuous–dashed line inversion of the second polygon seems to confirm this last difference. The fact that the «economic viability» score of family farms goes up while that of AF farms goes down when agroecological family farms are grouped with AF farms, may imply that the financial management of AF farms is different from the one of normal agroecological family farms. The financial condition of all investigated AF farms was supported by either remunerative off-farm or side activities rather than state funds. Two AF farms received significant additional incomes from AF training courses, one farm was totally financed by an eco-friendly real estate foundation, one received financial support by the dairy farm of the same farming enterprise, one AF farmer had an off-farm job, another had savings from his former non-farm-related job. All this may confirm that AF and family farms have different strategies to make their business economically sustainable. This consideration supports our initial decision to classify AF farms separately from family farms, regardless of the conventional, organic or agroecological nature of family farms. Indeed, some AF farms did not comply with the Brazilian definition of «family farm» as they were run by single people or workers of different family units.

Many of the interviewed family farmers could not correctly define «sustainability» but consciously or involuntarily performed agroecological and environmentally sustainable practices such as minimum tillage, cover cropping, and organic fertilization, similar to AF farmers. Some others avoided PPPs and planted Cerrado native tree species. Nationally, it is hard to estimate the number of family farms that carry out agroecological farming. The IBGE (2017) agricultural census grossly indicated that 2.9 M Brazilian farms (i.e. 58% of the total) do not use fertilizers and more than 590,000 (i.e. 12%) use only organic fertilizers. Yet, our interview findings revealed that almost all family farmers use organic fertilizers (e.g. cattle or chicken manure, urea, food residuals, green leaf manure), and some of them used chemical fertilizer (e.g. phosphorus compounds and ammonium sulfate). Moreover, they integrate fertilizers applications with limestone and mineral rocks. Nonetheless, most AF farmers also used organic fertilizers, limestone, and mineral rocks. More than 550,000 farms (i.e. 19%) in Brazil perform zero-tillage farming and about 1.1 M farms (i.e. 36%) minimum tillage farming. Approximately 3.4M farms do not use PPPs (i.e. 65%). These significant numbers are consistent with our findings, and have been driven by the success of agroecological production in terms of sustainability, productivity, ability to be participatory, innovative, cultural, socially just and economically viable (Gliessman, Engles, & Krieger, 1998; Altieri 2018).

All three sustainability comparisons showed that soy farming, as it is currently done, is unsustainable for the *Cerrado*. Its environmental sustainability is either critical or problematic, except in the «water use» theme. This exception, however, must be considered cautiously as not all RISE water-linked questions could be answered (e.g. «Has water quality deteriorated during the past 5 years?»). Several studies have revealed that soy farming reduces water infiltration. This is because intense machinery use causes soil compaction, which leads to soil structure degradation (Hunke, Mueller, Schröder, & Zeilhofer, 2015). Also, our results showed that soil compaction is one of the major environmental issues caused by soy farming. Soil erosion, instead, is apparently not recorded. Even though we did not find any evidence of ongoing water and/or wind erosion, we cannot exclude that one of the three soy farmers deliberately chose not to report soil erosion issues. Also, PPPs are often found in surface and groundwater. This is mainly due to wind drift after PPP application with airplanes (Laabs, Amelung, Pinto, Wantzen, Silva, & Zech, 2002), direct water runoff from the soy fields (Casara, Vecchiato, Lourencetti, Pinto, & Dores, 2012), or the absence of riparian buffer strips (Nogueira, Dores, Pinto, Amorim, Ribeiro, & Lourencetti, 2012).

Other than the «water use» theme, RISE was generally incapable of rolling out partial theme scores (e.g. the «quality of life» theme for soy farms) when we could only partially feed the software. This rigidity of RISE underlines its scientific validity - as erroneous data interpretations are limited - but represents a weakness when data cannot be retrieved from farmers, either because they do not have the information or do not want to deliver it. In fact, one soy farmer declined our interview, and another one was reluctant to provide environmental data. The low score obtained by soy farms on the «material use & environmental protection» theme reflects their critical use of PPPs and fertilizers. These, and in particular glyphosate, often comply with the thresholds set by the Brazilian legislation but drastically exceed the stricter European ones (Hunke et al., 2015; Székács & Darvas, 2018). Soy farms score extremely low in the «energy & climate» and «biodiversity» themes. In line with Garret & Rausch (2016), they could reduce their greenhouse-gas emissions and impact on biodiversity by adopting multi-functional agricultural systems. Livestock rotations would help recover soil organic matter, leguminous crops and forages rotations would reduce the need for synthetic fertilizers (Garrett & Rausch, 2016).

Also, the social sustainability of soy farms is critical. Despite the higher economic profitability, the wage and income level of soy farm employees is as critical as AF and family farms, and the «working hours» score is even lower. That is due to the extended working hours that dayworkers spend during the planting and harvesting period. In contrast to what Ioris (2017) denounced in Mato Grosso, we did not record any brutal appropriation of the commons, cases of slavery, forced labor or violent social conflicts connected to soy farms in Tocantins (Ioris, 2017).

Soy farms are extremely sustainable when it comes to money. They have an optimum liquidity and profitability level, which allows them to easily return by the end of each fiscal year the million *reais* credit to buy fertilizers and PPPs to farm genetically modified soybeans. This credit is typically received from the government-controlled Bank of Brazil. In fact, the national government and agribusiness system are inter-dependent. Agribusiness farming - including production, processing, distribution, supply, logistics, research, technical and financial consultancy - contributes to more than 20% of the national GDP (Klein & Luna, 2018), provides tax revenues and export revenues that raise the value of the Brazilian currency (Garrett & Rausch, 2016). This dependence has hijacked Brazil's economy and left little space for other farming systems. It has helped unify the interests of rural groups, favored a group of political elites in charge of agri-neoliberal reforms, renovated processes of class domination and created social exclusion (Ioris, 2017). That is because agribusinesses and soy farms require little workforce as compared to the cultivated surface. So, they do not fulfill the social need for employment in the countryside, do not stop urban immigration and their high profits remain with only few landowners and managers (Cassel & Patel, 2003).

Concerning the economic viability, soy farms score low only on the «stability» indicator, as they can be heavily affected by extreme weather events and market fluctuations. To impede these risks, well-established soy farms store beans from previous harvests. Stored beans can serve as economic reserves and be sold when market conditions are favorable (*e.g*. when international prices are higher or the yields of U.S. soy farms are bad; USITC, 2012).

Finally, soy farms have a worse «farm management» sustainability degree – which consists of the indicators «business goals, strategy, implementation», «availability of information», «risk management», «resilient relationships» - than the two other farm types. As for the Bolivian soy farm, the biggest management issue was the lack of information about the exact amount of fertilizers and PPPs used. As for the Brazilian soy farms, the biggest issue was the partial unawareness of a farm manager about his farm mission. On average, soy farm managers believe that a «good farm» must do a «good job» in terms of crop productivity and profits, which in turn will sustain the enterprise and provide satisfying wages to employees. Farm managers also believe that the atmosphere at the enterprise should be positive and without internal conflicts.

Table 3 summarizes the sustainability levels, similarities and differences of the three systems.

The difference between AF and family farms is minimal, either because of the young age of most investigated AF farms or because it cannot be fully expressed through a RISE assessment. Looking at the farmer rather than the farm, AF and family farmers have very different missions and degrees of education. All AF farmers had at least a high school diploma, while some family farmers did not even complete primary school. Most AF farmers received their farming education aside or after quitting their main occupation. They have a smaller farming heritage compared to family farmers and less years of farming experience. Nevertheless, their farms were thoroughly designed following well-defined agroecological principles which they acquired in AF training courses. This confirms that also AF farmers have solid farming knowledge. Their farms did not emerge from implementing a set of farming practices only (e.g. crop rotation, composting, cover cropping, etc.). They are, and will be, designed as Nicholls et al. (2017) define as the ultimate agroecological system: *i.e.* «an ecological infrastructure that through plot- to landscape-scale diversification, encourage[s] ecological interactions that generate […] essential ecosystem services' '. Finally, family farms must be designed as functional food systems that improve their economic and social sustainability.

The third sustainability polygon comparison highlights the profound difference between large-scale agribusiness farms and smallholder farms in all sustainability dimensions, making it clear that the latter is by far more sustainable than the former. This outcome is in line with Ortega (2006), for whom smallholder farms provide an acceptable quality of life quality, recycled materials, uses natural and economic resources

Table 3. Comparison of the environmental, social and economic sustainability, and good governance of family, AF and soy farms

	Environmental sustainability	Social sustainability	Economic sustainability	Good governance
Family farms	- Overall **positive** despite unawareness of the meaning of sustainability - Space for improvement on «energy & climate».	- «Quality of life»: **positive** - «Working conditions»: **critical** because of low wage and overwork.	- **Critical** because of low liquidity and profitability - Depend on state credits.	- **Positive** because of resilient relations, good livelihood security and diversification strategies.
AF farms	- Overall **positive**. As sustainable as family farms - Smaller score than family farms on «energy & climate» because of worse monitoring and farm at initial stage.	- «Quality of life»: **positive** - «Working conditions»: **critical** because of low wage.	- Barely **positive** because of low liquidity. Higher profitability than family farms - Do not depend on state credits. Additional incomes from side or off-farm activities.	- **Positive** because of good cooperation - Slightly smaller score than family farms because no technical advice from official farming institutions.
Soy farms	- **Critical**: «soil use», «material use & environmental protection», «energy & climate» - **Problematic**: «biodiversity» - **Positive**: «water use».	- **Critical** because of employees' low wage and overwork of dayworkers.	- Highly **positive** - Profits go only to a few people - Economic «stability» threatened by market fluctuations and extreme weather events. Risk management measures are adopted.	- **Critical** because of information lack on exact number of PPPs to use, and manager's partial unawareness of farm's mission.

effectively and moderately. The huge gap between the two polygons hints that soy farms will hardly match the sustainability level of smallholder farms. Consequently, they cannot represent a sustainable farming option for the Cerrado. Smallholder farms (i.e. AF and family farms) are instead the winners of our sustainability assessment. It is true that family farms depend on state funds and AF farms are not socially sustainable, but they provide better working conditions and more employment than soy farms. Also, soy farms are usually not or barely incorporated in the primary and secondary sector of local economies. So, the farm's economic profits coming from globalized transactions do not offset the social-environmental costs that the local society pays for (Rocha & Foschiera, 2018). Soy farms' main driving forces are economic factors, the legitimation or support of national politics and political pressures from importing countries (Ioris, 2017). They have lost connection to their environmental foundation. Family farms, instead, have preserved it: they represent a coevolution of culture and nature (Francis et al., 2003). Their ability to keep up with the environmental sustainability performance of AF farms is a solid proof of this statement. Such reflections should be considered by Brazilian governmental bodies that often portray the advance of agribusiness as the embodiment of an emerging economy (Ioris, 2017), develop plans based on soy expansion predictions and call for actions to improve the sustainability of family farming (Consórcio CP – Chess, 2018). Efforts should be put to improve those sustainability themes of family and AF farms that are not yet at a positive sustainability degree (i.e. the «energy & climate», «working conditions» and «economic viability»), rather than supporting the expansion or new establishment of unsustainable soy farms.

V. Conclusion

Soy farm managers are rather unaware of the TBL concept. Their understanding of sustainability is restricted to the economic viability of the farm and the satisfaction of employees and landowners. Using a sustainability performance tool may not be the best way to discuss sustainable farming with them. As they are more sensible to market fluctuations and unpredictable weather events, a better way could be to analyze how soy farms are economically impacted by the climate crisis. Smallholder farms, here AF and family farms, have the best sustainability performance in the *Cerrado.* For further research on smallholder farms, we recommend investigating the potential of AF farms to become a widespread sustainable alternative to the Brazilian dualism and on their concept of «regenerative farming». We also recommend using a variety of assessment tools to better understand the differences and similarities between AF and family farms.

RISE proved to be a valid indicator-based tool to evaluate the sustainability performance, as expressed by the TBL, of single farms. Thanks to its well-developed farming database, it was able to adapt to three highly different farm types and provided truthful outcomes. Discussing outcomes with farm managers would allow us to double-check our sustainability polygons and influence their farm management. To improve the quality of the outcomes, we suggest verifying whether the RISE indicator «water use intensity» is correctly tailored to AF systems. That is, to verify whether the indicator reference values and calculation sequences adequately consider the water recycling potential of a *multistrata* AF system. Yet and due to our valuable results, we encourage researchers to consider RISE as a novel tool for timely and sound sustainability assessments in the *Cerrado*.

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