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Sustainability Assessment of Intensive Agriculture in Argentina. Focus on Upstream (Emergy) and Downstream (Emissions) Environmental Impacts.

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Abstract

After the Industrial Revolution the agricultural sector was one of the most transformed. The activity releases CO2 and generates a change in land use, advancing on ecosystems with native vegetation, which function as carbon sinks. The model of industrial agriculture is highly dependent on inputs in the form of materials and energy, mainly fossil fuels but there are other hidden constraints that rely on the environmental quality of resources used and the extent of downstream impacts generated by their use in a process, that do not emerge clearly from investigating only material and commercial energy. As a consequence, additional investigation with alternative approaches, like emergy and emission assessment, is needed. In this article the analysis focuses on the emergy assessment and pollutant emissions by soybean production in two Argentine localities with environmental differences, one in the province of Buenos Aires (Rojas) and the other in the Chaco province (Charata). We used an upstream method (Emergy Accounting) and a downstream method (CML2 baseline 2000). Both sites show Renewability smaller than 35%. The total amount of CO2eq emitted in Charata is 0.80 ton/ha/yr and 0.81 ton/ha/yr in Rojas. However, the local conditions, the impact of industrial agriculture is very high. In Chaco region, possible regulations that establish the afforestation of certain areas around soybean crops should be analyzed, to operate not only as carbon sinks but also as barriers for agrochemical drift.

1 Introduction

Since the Industrial Revolution and the use of fossil fuels, the world suffered huge transformations. An important consequence of this process was the release into the atmosphere of increasing amounts of CO_2 and other greenhouse gases (GHGs) (Zhang et al., 2008; Pardos, 2010). GHGs listed in Annex A of the Kyoto

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Protocol (1998) are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (F_6S).

Before the Industrial Revolution, the concentration of CO_2 in the atmosphere was less than 280 parts per million. The burning of fossil fuel for energy and the clearing of forests for agriculture, building material, and fuel has led to an increase in the concentration of atmospheric CO_2 to 388 parts per million in 2010 (Ryan et al, 2010). By incorporating hydrocarbons, the exploitation of natural resources increased significantly, with enormous consequences on global balances of the planet. According to Toledo (1998), the great leap from hunter-gatherers to industrial societies can be assessed by the intensity of their energy consumption. Daily consumption per capita of these early societies was around 2000 kcal. Since agriculture, the consumption increased between 10-20,000 kcal per capita, and today it is between 120 and 200,000 kcal per day per capita. In the words of the author: "The industrial civilization has relied on the intensive use of fossil fuels, metals, chemical and plastic substances derived from hydrocarbons. Each of these uses has a huge range of environmental disturbances" (Toledo, 1998).

Agriculture was one of the most transformed sectors. Animal power and human labor were replaced by machines. In the 1940s, with the Green Revolution (Beltran, 1971), agriculture became increasingly dependent on petroleum supplies. This process involved the use of genetic varieties of higher performance, combined with irrigation and massive use of chemical fertilizers, pesticides, herbicides, tractors and other heavy machinery. In the 1990s, a "new" Green Revolution, or industrial agricultural model arises. Giampietro and Mayumi (2009) define the paradigm of industrial agriculture as the idea that a massive use of technology (capital) and fossil energy in agriculture is justified in order to achieve two key objectives: boosting the productivity of labor in the agricultural sector and boosting the productivity of land in production. For this reason, the adoption of this paradigm implies the abandonment of the traditional, integrated systems of agricultural production, which used to give top priority to the reproduction of the rural community and nutrient cycles. Thus, it requires a linearization of flows of nutrients. Such a linearization is possible only because of technical inputs, such as commercial seeds (hybrid or genetically modified seeds with selected properties), pesticides and machinery, which are heavily dependent on fossil energy for their production and/or utilization. As a result, agricultural produce no longer has any relation to local varieties and local seeds on which the traditional farming system was built.

The fossil fuel burning has disturbed the carbon cycle. Moreover, one of the consequences of the agricultural frontier advance into areas with environmental constraints for agriculture is deforestation, which also implies CO_2 emissions. Among other consequences, an increase of solid, liquid and airborn emissions, a reduction of biodiversity, more eroded soils and loss of ecosystem services are becoming day by day more visible (Rótolo et al., 2014).

The biome vegetation works as a carbon sink, and the assessment of interference with carbon sequestration by industrial agriculture is required, also taking into account what was the ecosystem replaced by crops (Dick, et al., 1998). According to FAO (2006) approximately 16 million hectares of forest are converted to other uses each year. This loss represents a fifth of global carbon emissions, making the change of land use the second largest contributor to global warming. Forests are estimated to sequester nearly 10% of current global fossil fuel C emissions (IPCC, 2007). By sequestering large amounts of atmospheric carbon, forests play an important role in the global carbon cycle (Luyssaert et al., 2007; Pardos, 2010) and in any initiative to fight against climate change (Parker, et al., 2009). According Pece et al. (2006), the sectors that modify the content of GHGs in the atmosphere are the energetic following by land use and forestry. The influence of forests in climate change occurs particularly by:

- The destruction of forest biomass by fire. With this action greenhouse gases are released and transferred immediately into the atmosphere.
- The transformation of forests into other cover types (such as agricultural cover).

Furthermore, the expansion of the agricultural frontier, mainly with soybean, causes a significant loss of native forest areas and increased fragmentation (Pengue, 2004), drastically reducing the capture and storage of CO_2 released by agricultural activities and forestry.

The objective of this study was to perform an integrated evaluation of soybean production in two Argentine localities with environmental differences, one in the province of Buenos Aires (Rojas) and the other in the Chaco province (Charata).

According to Ulgiati et al. (2006) all impact assessment methods can be divided in two broad categories: those that are focused on the amount of resources used per unit of product ("upstream" methods), and those that deal with the consequences of the system's emissions ("downstream" methods). The former can provide invaluable insights into the hidden environmental costs and inherent (un)sustainability of even seemingly "clean" systems. On the other hand, downstream methods are often more closely related to the immediate perceived impact on the local ecosystem, and can unveil large differences between systems with similar upstream performance (Ulgiati et al., 2006).

To study a productive system, the material and energy demands are very useful to investigate the resource constraints to the process (Schandl et al., 2016; Ulgiati et al., 2011; Moncada, 2006) but there are other constraints (most often hidden) that rely on the environmental quality of resources used (namely their production cost by nature and renewability) and the extent of downstream impacts generated by their use in a process, that do not emerge clearly from a Material Flow Analysis or Embodied Energy Analysis. As a consequence, additional investigation with alternative approaches, like emergy and emission assessment, is needed. In this study, we used an upstream method, the Emergy Accounting (EMA) and a downstream method, the CML2 baseline 2000. While EEA and MFA methods analyze the material and fossil fuel energy depletion of local and regional natural resources (water, minerals, fuel), EMA expands the scope by accounting for contributions of the free environmental, labor and economic flows that are important inflows to the process (Rótolo et al., 2014).

The hypothesis that guides this research is that, due to environmental differences between regions and the environmental fragility of Charata, it is expected that the impact of agricultural activity is higher in the Chaco region. The prediction derived from the hypothesis is that total emergy used is higher in Charata than in Rojas. This would be due to a higher use of inputs to offset environmental limitations. Finally, from published data, the surface of native vegetation that would be necessary to absorb the direct CO_2 emissions was estimated.

2 Materials and Methods

2.1 Study areas

Two Argentine agricultural localities were selected, one in the Pampas region (Rojas, Buenos Aires Province) and the other in the Chaco region (Charata, Chaco Province). The data come from semi structured surveys of middle-income producers in each locality, and the time window is one year, with reference to the 2009-2010 campaign.

The main differences between the two locations are climate, native vegetation, and land use history: in Rojas, the average annual rainfall varies between 1000 and 1200 mm (Matteucci, 2012) while in Charata varies between 650 and 900 mm (Morello, 2012). In the last site, although rainfall allows rainfed agriculture, water is a limiting factor and drought years are not rare. Agriculture in the Pampas region advanced over pastures, and has a much older history of agricultural tradition. The implementation of agriculture as a significant activity in the Pampas region occurred between 1890 and 1910 (Solbrig, 1997), while in the Chaco region the transformation is more recent. The process called "pampeanization of the Chaco" started in the 1970s (Morello et al., 2007), and even though the first ecosystems converted to agricultural use were the savannahs, later the crops moved over forests, reducing substantially the "Three Quebrachos Forest" formation, which is the predominant ecosystem in the eastern edge of the Chaco Seco, where Charata settles. *Aspidosperma quebracho blanco*, *Schinopsis lorentzii* and *Schinopsis balansae* coexist in this forest (Adámoli et al., 2011).

2.2 Emergy Accounting

Emergy Accounting (EMA) accounts for the direct and indirect solar available energy required to make a given product or to support a given flow. Emergy inflows express the amount of solar energy required to produce the resources needed to drive a process. This solar base of reference (named solar equivalents joules, or seJ) (Odum, 1986, 1988, 1996, 2000) allows the method to account for free environmental inflows such as solar radiation, wind, rain, as well as the economic and labor contributions to the process (Brown and Ulgiati, 2004a). In this method intensities are named UEV (Unit Emergy Values, seJ/unit).

The ecosystems are self-organized and self-regulated, have a hierarchical organization and are thermodynamically open (Campbell et al., 2005; Pulselli et al., 2011; Brown et al., 2001). This means that they exchange matter and energy with their environment, which is reflected in a large number of circulating flows into and through the system. From this variety of flows, those that are relevant to the analysis and objectives are chosen, and can be schematically represented by a flow diagram, using the systemic language developed by Odum (1986, 1988, 1996, 2000). It is very important to define the limits of the system, because they allow to analyse what goes and what comes out of it, besides the internal circulations.

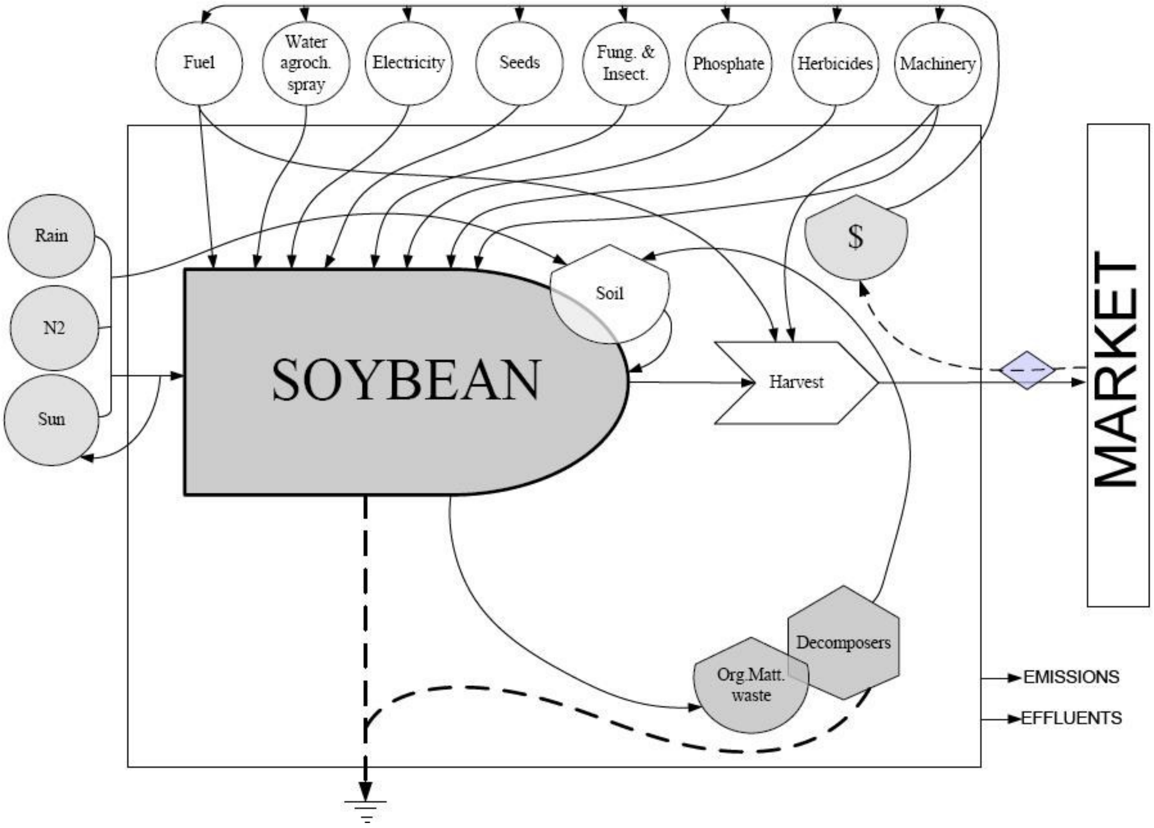

Fig. 1. system diagram of soybean production in study areas. Own elaboration after Odum (1986, 1988, 1996, 2000).

On the left, Figure 1 shows inputs from nature, represented by rain, atmospheric N_2 and sun. At the upper limit, all entries from economics and obtained from money are shown. On the right, there are the system outputs, the desirable (product in exchange for money) and unwanted (emissions and effluents). Finally, the outputs at the bottom end refer to the thermal losses of living systems.

Some indicators and emergetic indices were calculated: the Renewability index (%R) is the percentage of renewable emergy used by the system; the Emergy Yield Ratio (EYR) is the ratio between the total emergy inflow and the emergy purchased from outside the system; the Environmental Loading Ratio (ELR) is the ratio between imported plus local nonrenewable and renewable emergies; the Empower Density (ED) is the ratio between the total input emergy and the area of investigation over time, the emergy sustainability index (ESI) is EYR/ELR (Franzese et al., 2013. Ottmann et al., 2013). The Specific Emergy (SE) is the total emergy per kg of soybean (Rótolo et al., 2014).

The general methodology that explains Emergy Analysis has been described in detail by Odum (1996) (Brown et al 2001), and subsequently reviewed by Brown and Ulgiati (2004a,b; 2010).

2.3 Gas Emission Inventory

Gas emission inventory supplies important information about global and local emissions. Due to current concerns about global warming, it is considered essential in any environmental assessment. There are two categories of emission: (i) Indirect gas emissions and (ii) Direct gas emissions. Indirect gas emissions are those related to production of materials used up by a system; those emissions generally are located far from the system location, nevertheless they cause global environmental load. To estimate the indirect emissions, firstly all materials used up by the system were converted into their oil equivalents, and then they were multiplied by the emission factors provided by EMEP/EEA (2013). Direct gas emissions are those caused locally by material and fuel burning. To estimate the direct gas emissions, only the diesel and gasoline burned in engines was accounted for. The emission factors for combustion in tractors (EMEP/EEA, 2013) were considered. Both, direct and indirect gas emissions supply information about total CO_2, CH_4 and N_2O released into the atmosphere (Agostinho and Ortega, 2012; 2013) (See Appendix).

The potential global warming is normally quantified by using global warming potentials (GWP) for substances having the same effect as CO_2 in reflection of heat radiation. GWP for greenhouse gases are expressed as CO_2-equivalents *i.e.* their effects are expressed relatively to the effect of CO_2 (Jensen et al., 1997). All emissions were transformed in CO_2 eq units, considering the following coefficients (IPCC, 2007): CO_2 eq = ($CO_2 \times 1 + CH_4 \times 75 + N_2O \times 289$).

2.4 CML2 baseline 2000

The CML2 baseline 2000 method (Centre of Environmental Science, Leiden University, NL, 2000), calculates the potential environmental damage of airborne, liquid and solid emissions by means of appropriate equivalence factors to selected reference compounds for each impact category. The impact potential for each category of the analysed system is calculated by multiplying all emissions by their respective impact equivalence factors, and then summing up the results.

In our study the analysed impact categories are:

- Acidification potential, expressed in gram SO_2 equivalent per gram of product;
- Eutrophication potential, expressed in gram PO_4^{-3} equivalent per gram of product;
- Human Toxicity potential, in gram 1,4-dichlorobenzene equivalent per gram of product (Ulgiati et al., 2006).

3 Results and Discussion

3.1 EMA and CML2 baseline 2000

The results were organized in a Table 1, where all the indicators for each method are shown. The normalization procedure was done with reference to the total impact generated for each indicator, the total impact was calculated by adding the values in all datasets; then, the value of the indicator for each system was divided by the total impact in order to calculate its fraction or percentage (Ulgiati et al., 2011).

Table 1. Performance indicators of soybean production

Product indicator	Charata	Rojas
Emergy, demand for environmental support[(a)]		
Specific Emergy (with L&S) (seJ/kg soybean)	2.13E+12	6.43E+12
Empower Density (with L&S) (seJ/ha/yr)	5.69E+15	6.43E+15
EYR (with L&S)	2.06	1.89
ELR (with L&S)	2.07	2.04
Transformity (with L&S)	1.45E+05	1.14E+05
Renewability (%R)	35%	33%
EIR (with L&S)	0.83	0.86
ESI (with L&S)	1	0.93
Climate change[(b)]		
Global warming (kg CO_2 eq/kg soybean)	2.93E-01	2.47E-01
Global warming (kg CO_2 eq/ha/yr)	780	800
Acidification (kg SO_2 eq/kg soybean)	2.67E-04	3.33E-04
Acidification (kg SO_2 eq/ha/yr)	7.12E-01	1.11E+00
Eutrophication (kg PO_4 eq/kg soybean)	5.37E-05	6.07E-05
Eutrophication (kg PO_4 eq/ha/yr)	1.43E-01	2.02E-01
Human toxicity (kg 1-4-dcb eq/soybean)	4.97E-04	5.64E-04
Human toxicity (kg 1-4-dcb eq/ha/yr)	1.33E+00	1.87E+00

Footnotes: (a) For calculations see Totino (2015; 2016); (b) for calculations see Appendix.

Figure 2 shows the gram productivity at the local level. Except for GWP the rest of the indicators reveal lower impact for Charata than for Rojas. This can be explained by the fact that Charata producers do not consider necessary the use of fertilizers.

Figure 3 shows the indicator values per unit mass, which discards the differences arising for the lower productivity in Charata; for this reason, the SE is higher. A larger impact due to emissions is observed in Rojas due to the use of fertilizers.

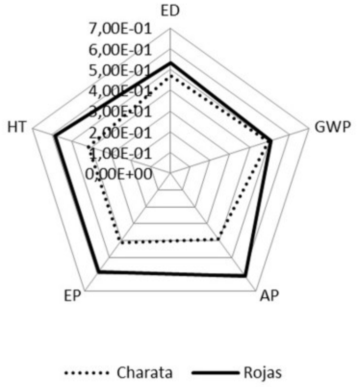

Fig. 2. Indicators per ha

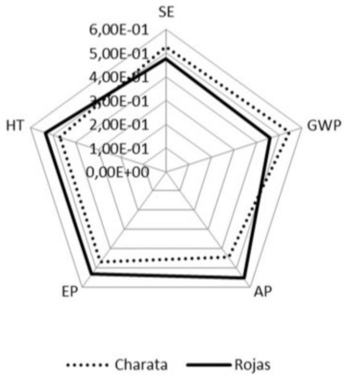

Fig. 3. Indicators per unit mass

The Emergy Yield Ratio (EYR) provides a measure of the appropriation of local resources by a process, which can be read as a potential additional contribution to the economy, generated by investing resources already available. The higher this value the more able is the process to exploit and make available resources from nature per unit of investment from economy (Franzese et al., 2013). Figure 4 shows that in Rojas, there is higher economic inversion per unit of product. Again, this is explained by the use of phosphate. The Environmental Loading Ratio (ELR = (N+F)/R) is designed to compare the amount of non-renewable and purchased emergy flows (N+F) to the amount of locally renewable emergy (R). The higher this ratio, the bigger the distance of the development from the natural process that could have developed locally without non-renewable investment from outside. In a way, the ELR is a measure of the disturbance to the local environmental dynamics, generated by the development driven from outside sources (Franzese et al., 2013). This value was 2.07 in Charata and 2.04 in Rojas, *i.e.*, the ELR is high in both sites. In Rojas, the renewability percentage (%R) is slightly lower (33%) than in Charata (35%).

The Emergy Investment Ratio (EIR) indicates the proportion of purchased resources from the economy in relation to the free resources from nature used by the production system (Franzese et al., 2013). In our results both sites present a value lesser than 1 (0,83 for Charata and 0,86 for Rojas). This indicates that although the free inputs of nature are greater than those purchased, the system is very close to using the same proportion of purchased and free inputs.

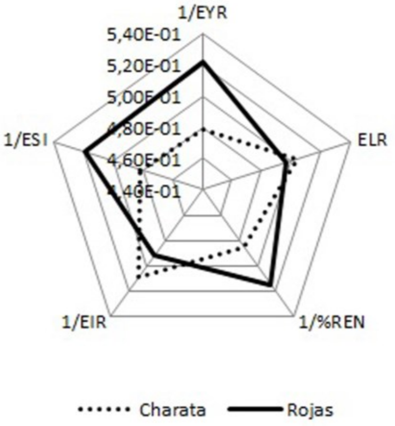

Fig. 4. Performance indicators

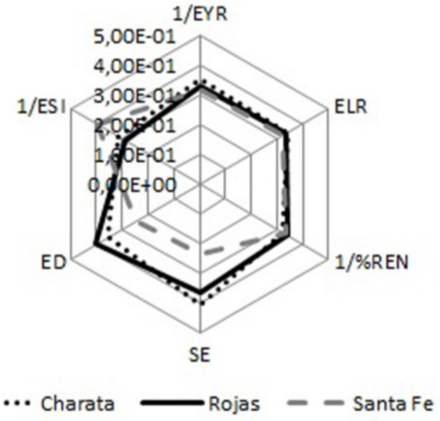

Fig. 5. Comparison between Charata, Rojas and Santa Fe in 2009 (Rótolo et al., 2014).

Finally, the emergy sustainability index (ESI) is an indicator that should give a high number when estimating the EYR against the ELR. A high EYR with a low ELR summarizes the attributes necessary to consider a production system as more sustainable than another (Ottmann et al. 2013). We obtained an ESI of 1 for Charata and 0.93 for Rojas.

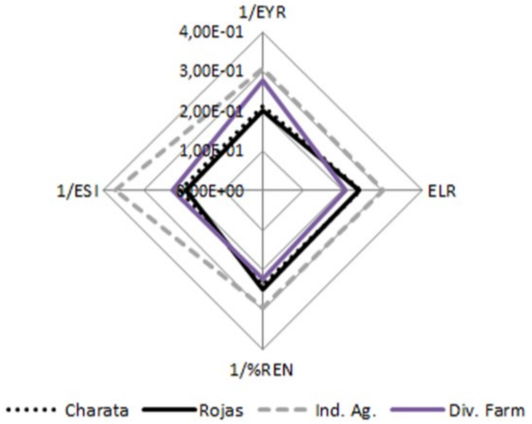

Fig. 6. Comparison between Charata, Rojas, an industrial agriculture farm and a diversified farm (Ottmann et al., 2013).

Our results confirm those of Rótolo et al. (2014), who analyzed soybean production in the Santa Fe province in the Pampean region in 2009 (Figure 5). The emergetic indicators are similar, except for the total emergy. In Santa Fe the total emergy is 1.23E+12 seJ/kg of soybean, while in our study area the values are

2.13E+12 for Charata and 1.93E+12 for Rojas. The comparison of our results with those of Franzese et al. (2013), for the Toledo river basin, shows that in the latter, total emergy was 2.06E+12 seJ/kg of soybean, which is in between the values for Charata and Rojas. The differences between our results and those of Rótolo could arise from the conversion factors used more than due to differences between agricultural models.

We also compared our results with those of Ottmann et al. (2013), who applied EMA both to an industrial agricultural production and to a diversified farm in the pampean region (Figure 6). It turns out that the industrial production presents the worst values for all the emergetic indicators, which result even higher than those for Charata and Rojas. The diversified farm shows the largest renewability and the lowest environmental impact, even though the economy inputs are higher than those of nature as compared to our results.

For a complete analysis of soybean production using EMA refer to Totino (2016).

3.2 Emissions

In Charata the largest emissions of CO_2 correspond to the oxidation of organic matter in the eroded soil, representing 84.5%. In second place stands diesel, with almost 10%, and finally, the herbicides with little more than 3%. The remaining inputs contribute little compared to the above, summing all less than 3% of the total. In Rojas, the greatest amount of CO_2 is also emitted by soil oxidation, with 80%, followed by diesel, with 9% and finally phosphate fertilizers (4.6%) and herbicides (3.75%). We highlight the weight of soil erosion in relation to CO_2 emissions, since it gives an idea of the impact of this type of agriculture.

Soil constitutes the largest pool of C and severe ecological disturbances could lead to important changes in net carbon storages (Bonino, 2006). As agriculture produces average soil organic carbon losses ranging from 15 to 40% in the top 1 m within 2-12 years following conversion of native vegetation to agriculture (Davidson and Ackerman, 1993; Evrendilek et al., 2004), important soil carbon emissions are very likely to occur in the Gran Chaco if the agricultural frontier continues to expand. CO_2 is taken as raw material for vegetation to build their biomass, and for this reason it is so important to preserve biomes such as forests, which act as carbon sinks. The flow of carbon between the different components of forest ecosystems and its eventual allocation to long-term storage pools (wood and soil organic matter), most likely varies across forests of different growth strategies (deciduous vs. evergreen), age, management regime, and climate (Luyssaert et al., 2007). The broad flexibility in forest C storage rates offers opportunities as well as challenges for those considering forests as an important component of strategies to mitigate rising atmospheric CO_2 (Gough et al., 2008).

Each forest type captures a particular amount of CO_2 per unit area. The area of native forest that would be needed to absorb the total gas emission caused by soybean production, can be calculate from emission data. To perform these calculations only direct emissions were taken into account. For Charata, oxidation of organic matter in the soil and fuel consumption are 94.5% of the total. In Rojas, the sum of both inputs represents 89%. Indirect emissions are not taken into account because they occur in places far from the study area, and while contributing to the global CO_2 in the atmosphere, it will not be absorbed by the vegetation surrounding the crops.

The total amount of CO_2 eq in Charata is 0.80 ton/ha/year, and 0.81 ton/ha/year in Rojas (only direct emissions). When searching for the CO_2 capture capacity of the Chaco forest, the problem is that it has not been measured. This depends on a set of tree and forest variables and requires the use of complex calculation methods (IPCC, 2000). After analyzing the studies in the world's forests, a value of net primary productivity was elected. This corresponds to semiarid forests, similar to those of Charata area (warm and dry weather conditions, seasonality environmental characteristics and relatively low foliar coverage). The value is 3.6 tons C/ha/year (Van Tuyl et al., 2005; Luyssaert et al., 2007). From the stoichiometric ratio 0.273 ton C/tn CO_2, it results that these forests capture about 13.2 tons CO_2/ha/year. Consequently, we estimate that for soybean production in Charata, an equivalent of 6% of the area planted should be preserved to absorb local CO_2 eq. The Ministry of AgroIndustry reports that in the 2009/2010 campaign 668,660 ha of soybean were planted in the province of Chaco (https://datos.magyp.gob.ar/reportes.php?reporte=Estimaciones). Thus, the surface of native forest needed in this province would be 40,120 ha. In 2011 the total forest area in the Chaco province was 4,629,534 ha (Montenegro et al., 2005; UMSEF, 2007, 2012), therefore this surface would be sufficient to absorb the calculated emissions of soybean. However, the forest must have certain characteristics of shape and continuity that allow them to function as carbon sinks. If industrial agriculture continues expanding on areas with native forests, it would be desirable to establish rules to preserve a minimum percentage. Provincial regulations, which have compliance lower to 40%, should be reviewed (Ginzburg et al., 2012). These authors recommend replacing the actual scheme of new farms established by the regulation of forest curtains, by a design based on landscape ecology knowledge, setting out the remnants of native forests in large blocks interconnected by biological corridors. The same recommendation should be made for Rojas, where there is no native vegetation to absorb the crop emissions. Also, new properties to be enabled do not exist, therefore the afforestation of certain areas around soybean crops should be analyzed as a possible strategy both to ameliorate the impact of industrial agriculture, not only as carbon sinks but also to mitigate the agrochemicals drift towards urban areas.

Charata area suffered a major clearance in recent years. Torrella et al. (2013) found that between 1957 and 2010 half of the forests disappeared in the study area. In addition, during this period the number of forest patches was doubled and their average size was reduced to 25% of that of 1957 (Torrella, 2014). Fragmentation is the modification of the natural landscape structure, and it involves the loss of spatial continuity of forests. This process is very important because it affects the effectiveness of conservation measures and management options (Montenegro et al., 2005).

In Rojas, the predominant native vegetation was grassland with dominance of graminoids and few herbaceous dicots, but due to the long agricultural tradition, until recently the native vegetation was found only in verges or under fences. Today, all vestiges of natural vegetation have been removed (Matteucci, 2012) and the crops are the unique vegetation cover. For example, in the Buenos Aires province the area planted with soybean occupied 18% of its total area during the period under review (https://datos.magyp.gob.ar/reportes.php?reporte=Estimaciones).

Renewable resources (such as rain, wind, and sun) are essential for any agricultural production and natural vegetation to perform photosynthesis, but those resources are not accounted for in the current monetary market, because they are considered free, and have not reached the status of scarcity yet. The conventional agricultural production systems use large amount of materials from economy, mainly those with high level of Embodied Energy. If all embodied energy, environmental services, and negative externalities were accounted for in the market prices, certainly the current conventional agricultural production would not be profitable (Agostinho and Pereira, 2013).

4 Conclusions

An agro-ecosystem under the model of industrial agriculture is “created” by the farmer, who determines that the system composition must possess a limited diversity of plants and animals; i.e. a very simplified structure compared to a natural ecosystem. From that logic, the strategy suggests that by reducing the competition, the available energy is channeled exclusively to the cultivation, which will benefit farmers with higher yields.

In our study, we show that the negative impact is related to the inputs, regardless the environmental conditions of the regions in which soybean production predominates. Our hypothesis that agriculture in the Chaco regions would require larger inputs to offset the ecological limitations is not achieved. Whatever the natural conditions of soils and climate, the industrial agriculture results in a heavy load for the natural ecosystems and this is reflected by the methods used. The expansion of the agricultural frontiers on forest lands like the Chaco region, has occurred (and continues to happen) with the clearing of native forests; which worsens the impact on climate change. It would be convenient to establish production strategies based on patterns of land conversion in order to prevent further deforestation, and conserve natural forest patches as providers of ecosystem services, such as carbon sinks, among others. The comparison among the various production systems would help the design of sustainable agriculture.

In brief, the information obtained confirms the idea that a production system with this large number of impacts cannot be considered sustainable in the long term. In words of Brown and Ulgiati (2010) "The prevailing world-view of many in the west seems to be that the only way to deal with the current global economic and environmental problems is to intensify the patterns of production and consumption that have produced them". The interest is focused only on increasing the cultivated area without regard that this advance occurs at the expense of native ecosystems, which mitigate the impact caused by the activity and provide many and varied ecosystem services. It is believed that solutions to these problems come from the hand of technology, when it might be time to start looking for alternative models that use fewer inputs and behave more like natural systems, devising new tools to make decisions about the management of natural resources and food production.

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Appendix

(1) Global emissions Charata and Rojas

- **CO_2 from eroded soil oxidation**

  % of Organic Matter in soil is 4 (Cavalett, 2008)

  % of water in OM is 30

  Oxidation of OM release 1.5 g of CO_2/g dry matter

  (1-0.3)(0.04)(1.5)=4.2E-02 g CO_2/g of eroded soil

  (4.2E-02)(1.7E+07)=7.14E+05 g CO_2/year

- **Gasoline** (trucks used exclusively in the field and travel to and from home)

Emission factors:

	CO_2	CO	NOx	SO_2	PM_{10}	N_2O	CH_4
g/Kg gasoline	3.18E+03	238.3	25.46	0.165	0.03	0.316	-

Source: EMEP/EEA (2013)

- Diesel emissions from agricultural machinery: Tractors, Harvester, Seeder and Sprayer machine

  Emission factors:

	CO_2	CO	NOx	SO_2	PM_{10}	N_2O	CH_4
g/Kg diesel	3.16E+03	10.94	35.04	0.02	1.74	0.136	0.055

Source: EMEP/EEA (2013)

- **Electricity**

In Argentina the energy matrix is approximately 40% oil, 40% natural gas, 10% nuclear and 10% hydro. The last two are not taken into account because they do not emit these pollutants. For example, in Charata total electricity used is 2.55E + 07 J/ha/year. By transforming it into units of oil equivalent the total energy demand is 7.44E + 01 MJ. From oil combustion in a power plant table is obtained that 1 MJ of electricity emits 73.3 g of CO_2. If only oil burned, the emissions would be 5.45 kg of CO_2, but according to the energy matrix alleged, oil accounts for 40%, therefore 2.18 kg of CO_2 released. The same for a gas burning in a central is done and emissions of both are added. For each pollutant, the procedure is repeated.

SO_2 emissions for each fuel are estimated assuming that all S in fuel is totally transformed into SO_2, using the following equation (CORINAIR, 2013):

$$E_{SO2}=2 \times KS \times FC$$

where

KS= S content in fuel (g/g of fuel)

E_{SO2}= SO_2 emissions

FC= fuel consume (g)

Emission factors for oil combustion in thermal power plant

	CO_2	CO	NOx	SO_2^*	PM_{10}	N_2O	CH_4
CORINAIR# g/MJ	73.30	5.00E-03	0.22	0.15	0.02	6.00E-04	3.00E-03

Source: CORINAIR and IPCC-EEA (2009)

Emission factors for natural gas combustion in thermal power plant

	CO_2	CO	NOx	SO_2°	PM_{10}	N_2O	CH_4
CORINAIR# g/MJ	56.10	0.04	0.09	2.90E-04	9.00E-04	1.00E-04	1.00E-03

Source: CORINAIR and IPCC-EEA (2009)

(2) LCA caracterization factors of emissions

		CO_2	CO	NO_x	SO_2	PM_{10}	N_2O	CH_4
Emission Categories								
Human Toxicity	g 1,4 dichlorobencene eq.	-	-	1.20	0.096	-	-	-
Acidification	g SO_2 eq.	-	-	0.5	1.20	-	-	-
Eutrophication	g PO_4 eq.	-	-	0.13	-	-	0.27	-

Source: CML 2000 method. Centre for Environmental Studies (CML), University of Leiden, 2001.

(3) Emissions flows Charata and Rojas (g/ha)

	CO_2	CO	NO_x	SO_2	PM_{10}	N_2O	CH_4
Charata	8.64E+05	4.01E+02	1.10E+03	1.38E+02	6.22E+01	4.14E+00	4.18E+00
Rojas	9.08E+05	5.22E+02	1.24E+03	2.27E+02	7.04E+01	4.65E+00	5.92E+00