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► **To cite this version:**

Marley Toloï, Rodrigo Carlo Toloï, Helton Silva, João Reis, Silvia Helena Bonilla. CO<sub>2</sub> Gas Emissions of Soybean Production and Transportation in the Different Macro-regions of Mato Grosso State - Brazil. IFIP International Conference on Advances in Production Management Systems (APMS), Sep 2019, Austin, TX, United States. pp.187-194, 10.1007/978-3-030-30000-5\_25 . hal-02419230

**HAL Id: hal-02419230**

**<https://inria.hal.science/hal-02419230>**

Submitted on 19 Dec 2019

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# CO<sub>2</sub> Gas Emissions of Soybean Production and Transportation in the Different Macro-regions of Mato Grosso State- Brazil

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**Abstract.** Brazil is one of the largest producers and exporters of soybeans and its production is mainly transported via the road system. The growing concern on the impacts caused by anthropogenic greenhouse gas emissions from agroindustry production as well as the commitment to international treaties supports the relevance of controlling and estimating their emissions. The objective of this work is to calculate the emissions of the main sources of GHG in the cultivation and transport of soybean production in the macro-regions of Mato Grosso, pointing out the main routes and modal integration of the production sites to the main Brazilian ports. For this purpose, the Life Cycle Assessment methodology was adopted. The results show that in most cases, the production of one kg of soybean emits more CO<sub>2</sub> than transportation of the same mass. This trend is more evident when the best actual combination of transportation modals is considered for each macro-region. The substitution of some highway stretch by water and/or railway has a positive effect, and it is possible to affirm that the use of multimodality, allows a significant reduction in CO<sub>2</sub> emission.

**Keywords:** Soybean, Transport, Emissions of greenhouse gases.

## 1 Introduction

Currently, the international market requires sustainable practices to minimize environmental impacts and reduce emissions of greenhouse gases (GHGs) [1, 2].

The Brazilian government launched in 2010 the program "Low Carbon Plan in Agriculture" coordinated by the Ministry of Agriculture, Livestock and Food Supply [3], regarding the reduction of carbon emissions.

Anthropogenic activities with intensive use of fossil fuels to support globalization, production and consumption lead to the emission of greenhouse gases. The sectors that most contribute to this increase in emissions are agriculture and transport, as highlighted by the Intergovernmental Panel on Climate Change [4].

Brazil is one of the largest soybean producers in the world and the largest exporter. Soybean supply chain is not only devoted to human and animal food products but also it is involved in biodiesel production by supplying the main source of raw material [5].

Mato Grosso which is located in the Midwest, stands out in the Brazilian scenario for high grain production, and it is expected to reach 32 million tons (30.8% of the national soybean production), [6, 7]. According to the Institute of Agricultural Economy of the State of Mato Grosso [8], 59% of the production is destined to the foreign market.

With an average distance of 2,000 kilometers for the main Brazilian ports, the State faces logistical problems (transportation costs, environmental impacts) [9–11]. The Port of Santos/SP represents 45.34% of exports and Porto de Barcarena/PA, 20.02%. Therefore, the ports of Arco Norte are a new alternative for the flow of production from the north of the country, according to the National Agency of Waterway Transportation [12].

The objective of this study is to calculate the emissions of the main sources of GHG in soybean cultivation and transport in the macro-regions of Mato Grosso, pointing out the main routes and modal integration for the Brazilian ports.

## 2 Materials and Method

### 2.1 Adopted Method

Life Cycle Assessment (LCA) identifies the environmental aspects of a particular product or service throughout its life cycle [13, 14]. There are four steps to achieve the results: goal definition and scope, inventory analysis (IA), impact assessment and interpretation. The present study is limited to global warming category assessment through calculation of the mass of CO<sub>2</sub>eq emissions for soybean production and CO<sub>2</sub> emissions for transport.

Two scopes will be considered. The first scope includes the emissions of agricultural activities for the soybean production; and the second, considers the CO<sub>2</sub> emission from diesel combustion, according to the type of modal adopted for transportation.

GHG emissions, expressed in CO<sub>2</sub>eq, are equivalent to the emissions of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O), corrected by the corresponding global warming potential (time horizon of 100 years) [4].

The functional unit of the present study is considered as 1 kg of soybean, in order to allow comparisons with other related studies.

### 2.2 System boundaries and delimitations

**Scope 1:** It considers emissions of CO<sub>2</sub>eq due to agricultural activities (those activities performed inside the gate). The activities are related to the production of soybeans and the combustion of diesel in all agricultural activities (soil preparation, planting, cultivation, harvesting, and limestone application) [4].

This study does not consider nitrogen fertilizer application since the presence of *Bradyrhizobium* enables the biological fixation of atmospheric nitrogen [15, 16], so direct nitrogen emissions due to the application are not accounted for. Calculation of GHG emissions due to herbicide and insecticide applications are not considered since they are negligible inside the gate.

**Scope 2:** It includes the identification of the main routes from its origin located at the main soybean producers' municipalities to the destination ports, as well as the transportation modalities used. From the identification of transport modals and distances traveled, the direct emission of CO<sub>2</sub> is calculated using the CO<sub>2</sub> emission factors for each type of mode used.

### 2.3 Presentation of the Macro-regions and Raw Data obtention

Studies carried out by the IMEA [8] divided Mato Grosso State into seven macro-regions from the point of view of agroeconomic. Data collection provided by IMEA [17] regarding agricultural production costs for the year 2018/2019 compose the IA.

Data selection for each macro-region depends on the scope adopted. When the scope 1 is considered, diesel and limestone inputs must be calculated. In order to convert raw data expressed as costs into units adherent with emission factors, the input prices for the different macro-regions were considered. Thus, to carry out the conversion to mass units, the cost of diesel oil was divided by the diesel price from the National Petroleum Agency [18]. Analogously, the cost of the limestone was divided by the price practiced in the State [19].

To carry out scope 2 analysis, the main routes to the main Brazilian ports were obtained from data from the Ministry of Transport, Ports and Civil Aviation, and authors, including highways (transshipment stations) from to waterways and railroads, as shown in Fig 1. [11,20-22].

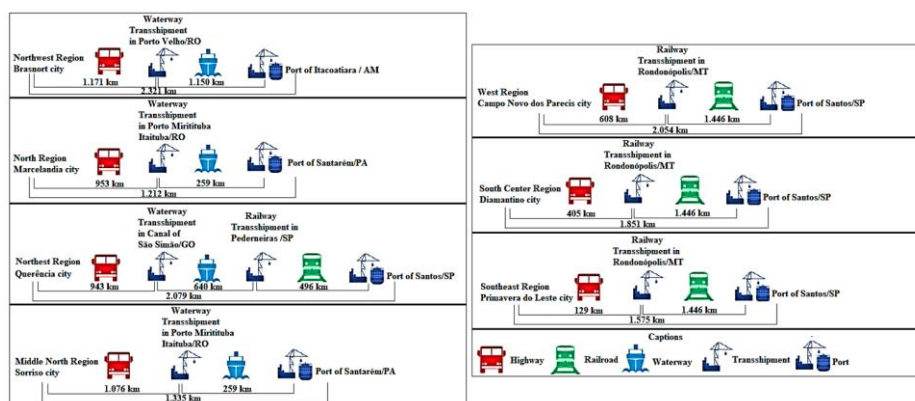


Fig. 1. Main routes used to export soybean produced in Mato Grosso State. Source: Authors.

The most productive municipality in terms of the largest soybean production [23], was considered as the representative one for each macro-region and thus it was set as the origin for distance to destination calculation. Thus, the emission factors for each

transportation model are used to calculate the emission of kg CO<sub>2</sub>/kg of soybean transported via the different intermodal routes. The ports considered (j) are: MA = Manaus; SL = São Luiz; ST = Santarem; SN = Santos; PR = Paranaguá;

## 2.4 Calculation of Emissions

The calculation of GHG emissions from diesel combustion and the application of the limestone used in the agricultural phase are carried out by multiplying mass and volume, respectively by the emission factors presented in Table 1.

**Table 1.** Emission factors for all inputs considering at scope 1 and scope 2. Source: the authors based on data from [4, 24].

Emission Source	Type of Emission	Unit	Emission Factor	Reference
Fuel Diesel	Direct	kg CO <sub>2</sub> eq/ L diesel	2,68	[4]
Limestone Application in soil	Direct	kg CO <sub>2</sub> eq/ kg limestone	0,48	[4]
Transportation modal Highway			0,11917	
Railway		kgCO <sub>2</sub> /t*km	0,0346	[24]
Waterway			0,018	

### Emission of Diesel

$$Emission\ of\ CO_2eq = Q_{diesel} \times FE \quad (1)$$

Emission of CO<sub>2</sub>eq is expressed in kg/kg soybean,  $Q_{diesel}$  corresponds to the quantity of liters of diesel/kg soybean, and FE to the emission factor, in kg of CO<sub>2</sub>eq per liter diesel.

### Application of limestone

$$Emission\ of\ CO_2eq = (M_{kg\ limestone} \times FE) \quad (2)$$

Emission of CO<sub>2</sub>eq is expressed in kg/kg soybean, M corresponds to the annual mass of calcium limestone in kg, and FE to the emission factor of calcium limestone

### Emission of CO<sub>2</sub> from diesel fuel for each Transportation Mode.

The calculations of CO<sub>2</sub> emissions from each Mato Grosso soybean route is composed by the combination of the distance (D), and CO<sub>2</sub> emission factor of each modal of transportation (FE<sub>i</sub>).

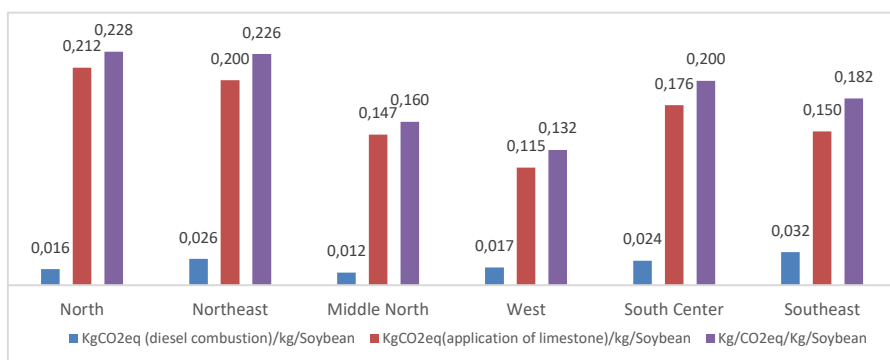
$$E_{jk} = \sum(FE_i * D_{jk}) \quad (3)$$

$E_{jk}$  corresponds to total CO<sub>2</sub> emission per municipality of origin  $j$  and port of destination  $k$ ; FE<sub>i</sub> corresponds to the CO<sub>2</sub> emission factor of each transportation modal  $i$ , in kg/t\*km; D is the distance traveled via each modal, in km;

### 3 Results and discussion

#### 3.1 From scope 1

Figure 2 compares the CO<sub>2eq</sub> emission during soybean production stage (inside the gate) for each Macro-region. Notice that for all cases, limestone application is largely the most impacting issue during production, while the diesel involved in culture practices ranges from 7% to 18% of the total emissions.



**Fig. 2.** Emission of CO<sub>2eq</sub> in the soybean farming activities in the different macro-regions of Mato Grosso Brazil. **Source:** Authors.

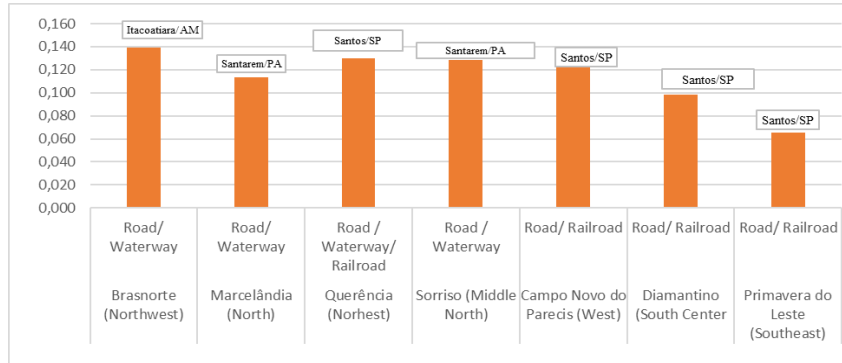
The limestone input represents the largest emission for agricultural activity in all cases. Since annually large amounts of limestone are used to correct soil acidity, and considering its contribution to global warming, it deserves a judicious evaluation of the required amounts to attain the proper pH. In this sense, the adoption of precision agriculture techniques could be useful.

The Northern and Northeastern macro regions show the largest emissions of CO<sub>2eq</sub>, 0.228 and 0.226, respectively. The Middle North and West result in the lowest emissions, varying from 0.160 to 0.132 kg of CO<sub>2eq</sub>/kg of soybean, fact that can be justified by the applied technology and improved agricultural practices [2, 25].

The average of emissions is 0.188 kg CO<sub>2eq</sub> kg of soybean produced. [1] shows comparable values, although it also includes the emissions corresponding to inputs production.

#### 3.2 From scope 2

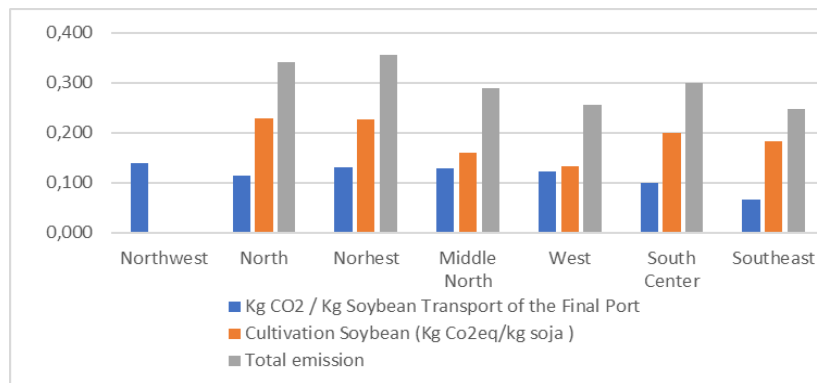
Although an interval of CO<sub>2</sub> emission values is obtained depending on the alternative routes covering each origin with destination ports, Figure 3 evidences the best routes (and combination of modals) for each macro-region. Santos is the destination port which shows the best route in terms of emission for four of the seven macro-regions. Each representative municipality is considered in the figure. The best-routes values range from 0.065 to 0,140 kg CO<sub>2</sub>.



**Fig.3.** Emission of Kg CO<sub>2</sub>/Kg of Soybeans/Transport of the Port Final. **Source:** Authors

The North-western macro-region (represented by Brasnorte) presents the largest emission. The road modal, which corresponds to a high emissions modal when combined with other transportation modals minimize emissions of the total route.

Figure 4 shows the comparison of production emissions and emissions in the route (CO<sub>2eq</sub> and CO<sub>2</sub>, respectively) for 1 kg of soybean.



**Fig. 4.** Comparison of CO<sub>2</sub> Emissions/kg of soybean in the production and transportation stages. **Source:** Authors

The results show that in most cases, the production of one kg of soybean emits more CO<sub>2</sub> than transportation of the same mass. This trend is more evident when the best combinations of transportation modals are considered for each macro-region (as in Fig. 4). The substitution of some highway stretch by water and/or railway has a positive effect, and it is possible to affirm that the use of multimodality, allows a significant reduction in CO<sub>2</sub> emission. It is important to mention that for transportation only direct CO<sub>2</sub> emission was considered by the emission factors, since it is the quantitatively most important gas emitted during combustion. Anyway, quantities of other GHG should be considered depending on type of engine, vehicle, maintenance, etc. This is not considered in the present work.

## 4 Findings and Conclusions

This study calculated the GHG emissions of agricultural activities and transportation intermodal routes towards the main ports for the different macro-regions of the Mato Grosso State.

Results at production shows emission values varying between 0.132-0.228, with an average of 0.188 KgCO<sub>2</sub>eq. It is evidenced that use of limestone is the largest emitter in the field. The adoption of more careful practices concerning limestone application according actual necessity will improve emission impacts. Public incentives for innovative technologies, such precision agriculture, should be promoted.

It has been observed that routes using road modal over 500 to 700 km increase the emission and must be combined with other transportation modals.

Public policies directed towards investments in logistics solutions that could assist in transportation infrastructure improvement could be a way to minimize environmental impacts.

## Acknowledgments

To the Coordination for the Improvement of Higher Education Personnel - CAPES, by the finance grant Code 001; to the Federal Institute of Education, Science and Technology of Mato Grosso (IFMT) to support the research.

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