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LCA of soybean supply chain produced in state of Pará, located on Brazilian amazon biome †

Thyago Brito [1,2]*, Rui Fragoso [2], Pedro Marques [3], Anabela Fernandes-Silva [3] and José Aranha [1,3]

[1] CETRAD - Centre for Transdisciplinary Studies, University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801, Vila Real, Portugal; j.aranha.utad@gmail.com
[2] CEFAGE – Centre for Advanced Studies in Management and Economics, University of Évora, 7000-809, Évora, Portugal; rfragoso@uevora.pt
[3] CITAB – Centre for Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes and Alto Douro, Quinta dos Prados, 5000-801, Vila Real, Portugal; anaaf@utad.pt; pmota-marques@gmail.com
* Correspondence: thyagob@utad.pt; Tel.: (+351) 926244991
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Abstract: Recently, Brazil turned the biggest soybean producer and exporter of the world. The state of Pará, located in the Brazilian amazon biome, was turned one of last agricultural frontier of the country, which increased positively the soybean cultivation along it is territory. However, it is necessary to know the associated environmental impacts along the supply chain. Thus, we are applying the life cycle assessment (LCA) methodology using *openLCA* software in two producing regions: northeast pole (Paragominas) and south pole (Redenção). Based on the cradle to grave scope, the Recipe Midpoint (H) and Intergovernmental Panel on Climate Change (IPCC) method of environmental impacts categories were used. To calculate the land use change (LUC), we used the BRLUC regionalized model (v1.3). The obtained results showed that LUC were the main responsible for the global warming potential (GWP) along all soybean supply chain, especially when the land occupied with tropical forest was changed for soybean growth. Despite the largest distance between origin and destiny (road + railway = 1306 km), the soybean produced in south pole (Redenção) is better shipped through the TEGRAM port of São Luis – Maranhão due to the use of multimodal platforms (lorry + train), allowing a more efficient logistical performance (greater loads of grains transported and less environmental impacts). The soybean produced in northeast pole (Paragominas) is better shipped through the ports around Barcarena – Pará due to the shortest distance by road (average 350 km) and hence less environment impacts.

Keywords: environmental impacts; grains; life cycle assessment; soybean production

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1. Introduction

In the last decades, soybean production has increased due to its use as an important source of protein and oil, which have been stimulated by the growing demand for feed, food and other by-products consumed worldwide [1]. Throughout 2019/2020, the USDA estimated a harvest of 122.63 million hectares destined for soybean worldwide, corresponding to a production around 339 million tonnes [2].

Only three countries (Brazil, USA and Argentina) are responsible for approximately 80.8% of all soybeans produced in the world. Among them, Brazil appears as the main soybean player in the world, having the largest cultivated area (36.9 million hectares), largest production (128.5 million tonnes) and is the largest export [2].

Located in the north of Brazil, the state of Pará is a new agricultural frontier in the country. In the 2019/2020 harvest, 1 859 million tonnes of grains were produced in an area of 607.4 thousand hectares with soybean cultivation. Pará has three producing regions, being the Paragominas pole and its municipalities the largest producer region with 339.5 thousand hectares. In the south of the state, the Redenção pole concentrates around 25% of soy production. In the region of Baixo Amazonas (Santarém pole), in west of the state, produces the remaining amount [3,4].

In 2006, under pressure from global retailers and non-governmental organizations (NGOs), the Brazilian Soy Moratorium (SoyM) was instituted in Brazil with the aim of achieving zero deforestation in the Amazon rainforest associated with soybean culture [5]. Thus, the soybean cultivated in the amazon biome areas recently deforested will not be marketed with the signatory trading's companies of agreement.

Agricultural activities are linked to greenhouse gas (GHG) emissions. Thus, the growing food production trends associated with global population growth, becomes essential to frequently evaluate the GHG emissions of crops [6]. However, other impact categories should be also monitored, such as human toxicity, freshwater toxicity, freshwater eutrophication and terrestrial acidification in soybean and sunflower cultivation [7].

Thus, the life cycle assessment (LCA) is an important tool that allows quantifying the environmental impacts throughout all stages of the supply chain. It can be considered from the raw material used along the production chain to the applied process (recycling or disposal) at the end of the product's life [8].

In LCA studies, we can consider two types of scopes: cradle-to-gate or cradle-to-grave, for a broader approach. Consequently, topics such as GHG emissions associated with the production of 1 kg of soybeans with a cradle-to-gate scope can be addressed [9] or even quantify the environmental impacts on the production of 1 kg of soybeans or 1 L of biodiesel involving the scope cradle-to-grave [10].

We cover all stages of soybean cultivation and inputs used. However, outside the scope of the cradle-to-farm gate, we also consider the transportation phase. This is which type of modal most affects the environment, as well as analyzing the distances from the site of production origin to the port of shipment. Thus, for those who are interested in the subject, we seek to describe the main hotspots of soybean supply chain in each category of environmental, having as reference two poles (Paragominas and Redenção) in the state of Pará, Brazil, using the LCA methodology.

2. Materials and Methods

2.1. Study area and crops

This study was based on the non-irrigated soybean (*Glycine max* (L.) Merrill) cultivation system in two production regions (pole): Northeast pole (Paragominas) and South pole (Redenção) in the state of Pará, Brazil. The average annual rainfall of the regions is, respectively, 1700 mm and 2000 mm per year [11].

2.2. Life Cycle Assessment methodology

This LCA approach follows the principles and framework [8], and requirements and guidelines [12] of International Standards Organization. The LCA method is appropriate to quantify the level of environmental impacts associated with the activities, identifying the main hotspots involved in each phase along the soybean supply chain. Their results can serve as guidelines, helping towards more environmentally friendly decisions, forward to minimize the more impactful activities on the environment.

2.2.1. Aim of the study

The focus of this study is to quantify the environmental impacts associated with the soybean supply chain in two production hubs in the state of Pará, Brazil using the LCA methodology. In addition, we seek to find which is the best destination (port of shipment) for the flow of harvested grains, considering the travel distances (Table 1) and the type of transportation modal involved.

Table 1. Traveling distances (in km), transportation modals and port of shipment.

Pole Origin	Road distance (km)	Multimodal platform	Railway distance (km)	Total distance traveled (km)	Port of Shipment
Paragominas (PGM)	351			351	BAR - PA[3]
Paragominas (PGM)	406	Porto Franco - MA[1]	783	1189	SLZ– MA[4]
Redenção (RDX)	827			827	BAR - PA[3]
Redenção (RDX)	305	Palmeirante - TO[2]	1001	1306	SLZ– MA[4]

[1] Transshipment in Porto Franco, state of Maranhão; [2] Transshipment in Palmeirante, state of Tocantins; [3] Barcarena, state of Pará; [4] São Luis, state of Maranhão.

2.2.2. *Scope of the study and crop management*

We apply a cradle-to-grave scope, without considering the stages of drying and warehousing grains, as well as the final consumption by customers. After farm gate, only the transportation of harvested grains from the farm to the two shipment ports is considered: port of Barcarena, in the state of Pará and port TEGRAM – Grains Terminal of Maranhão (acronym in Portuguese), located in São Luis do Maranhão. Our functional unit (FU) is 1 kg of soybean. In the agricultural phase, the inputs flows (production factors) were approached (Figure 1).

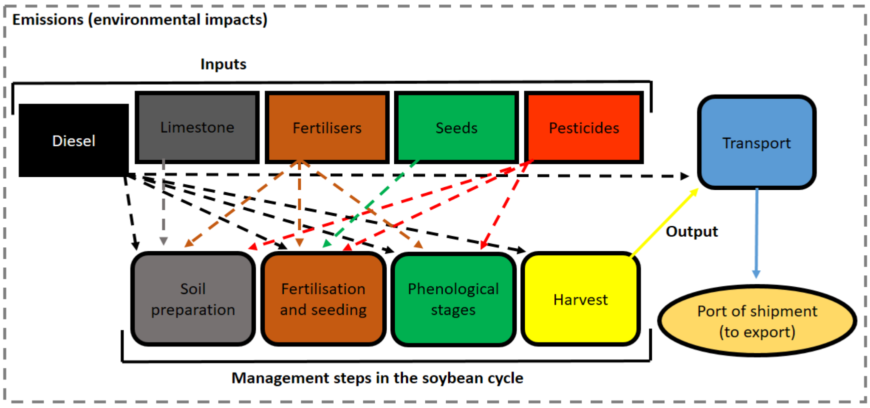

Figure 1. Supply chain flowchart for the life cycle of soybean crops.

Commonly in the region, NPK chemical fertilizers are used in sowing. However, as potassium is a salt, this fertilizing should be until 70 kg $K_2O.ha^{-1}$ to minimize the risks of stress on crop development, and hence affecting the uniformity of the population and their yield. Thus, if necessary and according to soil analysis, just do a complement of K_2O fertilizer by using a broadcaster a few weeks before sowing or 30 days after sowing. This procedure also aims to avoid losses of K_2O for leaching, mainly in sandy texture soils.

It is known that soybean is a *Fabaceae* family plant, capable to convert gaseous nitrogen from the atmosphere into NH_4^+ through a symbiotic relationship with N-fixing bacteria. Therefore, all farmers inoculate *Bradyrhizobium japonicum* in seeds before the sowing. However, the impact of inoculation was not considered in our inventory. A little bit of chemical nitrogen is used in the NPK formulation (7 kg $N.ha^{-1}$) to favor the initial growth of the plants. Generally, the tropical soils are poor in phosphorus. Thereby, in the soybean management it is used in the region 100 to 125 kg of $P_2O_5.ha^{-1}$.

In relation to the spraying along crop cycle, usually 4 fungicides, 2 insecticides and 1 to 3 herbicides (pre and post-emergent) are applied against diseases, pests and for cleaning weed in the crop field, respectively. These operations correspond to a range of 7 to 9 pesticide applications.

2.2.3. Software, database and LCIA method used

The *openLCA* software was used for information processing. Inputs and outputs flows of the process were extracted from French Life Cycle Inventory (LCI) database Agribalyse (v.3). We used average inventory values from four farms, and two life cycle impact assessment (LCIA) methods were applied: Recipe Midpoint (H) and IPCC 2013.

2.2.4. Land Use Change (LUC)

To calculate the LUC, we used the BRLUC regionalized model (v1.3) by [13], considering a 20 years temporal coverage (1999-2018) associated with the expansion of the planted area and other soil uses in Pará state. The model considers the influence of possible transitions in different land uses, estimating three emission scenarios: (I) minimum, (II) maximum and (III) proportional rate. To estimate scenarios (I) and (II), BRLUC considers the allocation of areas and emission rates using the simplex method based as a linear programming problem.

3. Results

Table 2 describes the inventories (inputs and outputs flows) used for the soybean production process, standardized for the FU of 1 kg of soybean (*fresh matter*). It is worth mentioning that the nitrate output (NO_3-) was calculated according to [14]. This proposed model (SQCB-NO3), considers the interactions between the nitrogen inputs in fertilization, nitrogen contained in organic matter in the soil, among other variables.

Table 2. Inputs and outputs of soybean production system in state of Pará, Brazil (FU 1kg of soybean).

Input	Amount	Output	Amount
Application of plant protection product, by field sprayer	0.00258 ha	Ammonia (NH_3)	0.00028 kg
Combine harvesting	0.00030 ha	Dinitrogen monoxide (N_2O)	0.00063 kg
Fertilizing, by broadcaster	0.00030 ha	Nitrate	0.02804 kg
Sowing	0.00030 ha	Nitrogen oxides	0.00013 kg
Tillage, harrowing, by spring tine harrow	0.00028 ha	Carbon dioxide, fossil	0.02502 kg
Tillage, ploughing	0.00010 ha	2,4-D	0.00045 kg
Transport, tractor and trailer, agricultural	0.01570 t*km	Acetamiprid	2.65000E-5 kg
Soybean seed, for sowing	0.01280 kg	Fenpropathrin	1.70000E-5 kg
Lime	0.04929 kg	Fluazinam	0.00011 kg
Urea, as N	0.00212 kg	Glyphosate	0.00061 kg
Phosphate fertilizer, as P2O5	0.03576 kg	Mancozeb	0.00034 kg
Phosphate Rock, as P2O5, beneficiated, dry	0.00212 kg	Prothioconazol	2.65000E-5 kg
Potassium chloride, as K2O	0.03030 kg	Pyraclostrobin (prop)	2.52300E-5 kg
Occupation, annual crop, non-irrigated, intensive	3.25298 m^2*year	Pyriproxyfen	7.60000E-6 kg
Transformation, from annual crop, non-irrigated	3.03030 m^2	Phosphorus	0.00128 kg
Transformation, to annual crop, non-irrigated, intensive	3.03030 m^2	Thiophanate-methyl	0.00011 kg
Energy, gross calorific value, in biomass	20.5000 MJ	Trifloxystrobin	2.27000E-5 kg
Carbon dioxide, in air	1.37808 kg	Soybean production	1 kg
2,4-dichlorophenol	0.00045 kg		
Pesticide, unspecified	7.44300E-5 kg		
Pyrethroid-compound	1.70000E-5 kg		
Pyridine-compound	0.00012 kg		
Glyphosate	0.00061 kg		
Mancozeb	0.00034 kg		
Triazine-compour	2.65000E-5 kg		
[Sulfonyl] urea-compound	0.00011 kg		

Table 3 describes 13 impact categories other than the 18 present in the Recipe Midpoint (H). These results do not support impacts from only five categories, which were not reported because the values are null.

Table 3. Life cycle impact assessment (LCIA) results at recipe midpoint (H) (FU 1kg of soybean).

Impact category	Unit	Total emissions	Main Hotspot
Agricultural land occupation (ALOP)	m^2 year	3.25298E+0	PS = 3.25298E+0 (100%)
Climate change (GWP100)	kg CO2-Eq	0.48312E+0	PS = 0.21154E+0 (43.8%)
Freshwater ecotoxicity (FET-Pinf)	kg 1,4-DCB-Eq	1.99383E-2	PS = 1.946E-2 (95.4%)
Freshwater eutrophication (FEP)	kg P-Eq	1.89967E-4	PS = 1.011E-4 (53.2%)
Human toxicity (HTPinf)	kg 1,4-DCB-Eq	0.10915E-0	MFPF = 4.81E-2 (44.1%)
Ionising radiation (IRP_HE)	kg U235-Eq	1.97907E-2	MFPF = 8.14E-3 (41.1%)
Marine ecotoxicity (METPinf)	kg 1,4-DCB-Eq	2.42444E-3	PS = 1.429E-3 (58.9%)
Marine eutrophication (MEP)	kg N-Eq	7.10465E-3	PS = 6.413E-3 (90.2%)
Ozone depletion (ODPinf)	kg CFC-11-Eq	2.82500E-8	MFCH = 7.59E-9 (26.9%)
Particulate matter formation (PMFP)	kg PM10-Eq	9.67280E-3	MFPF = 3.24E-4 (29.6%)
Photochemical oxidant formation (POFP)	kg NMVOC-Eq	2.03110E-3	MFCH = 6.67E-3 (32.8%)
Terrestrial acidification (TAP100)	kg SO2-Eq	2.57782E-3	PS = 7.623E-4 (29.6%)
Terrestrial ecotoxicity (TETPinf)	kg 1,4-DCB-Eq	0.01326E-0	PS = 1.243E-2 (93.7%)

PS = production system, MFPF = market for phosphate fertilizer; MFCH = market for combine harvesting.

All pesticides (active principle) used in field must be placed as output of the production system (agricultural phase) in the category emissions to soil. Their chemical groups were placed as inputs. Ammonia, nitrogen oxides, dinitrogen monoxide and carbon dioxide fossil emissions were calculated as [15] - guidelines. The yield of soybean in each site is 3300 $kg.ha^{-1}$, considering 115 days for the soybean cycle of cultivation.

In addition to the total values for each impact category considering the FU production process, the main hotspots (most impactful process in the category) were also highlighted, with results and percentage contributing to the total impact category.

Soybean produced in each production pole has two possible destination routes. Therefore, CO2 emissions per kg soy (*fresh matter*) along routes were calculated. Both routes to the port of Barcarena were carried out by lorry transport, while the routes to São Luis (TEGRAM) involved lorry + railway. Thus, the emissions from Paragominas to Barcarena are lower than to São Luis, while the converse is observed in Redenção, where the emissions to Barcarena are higher than to São Luis (Figure 2).

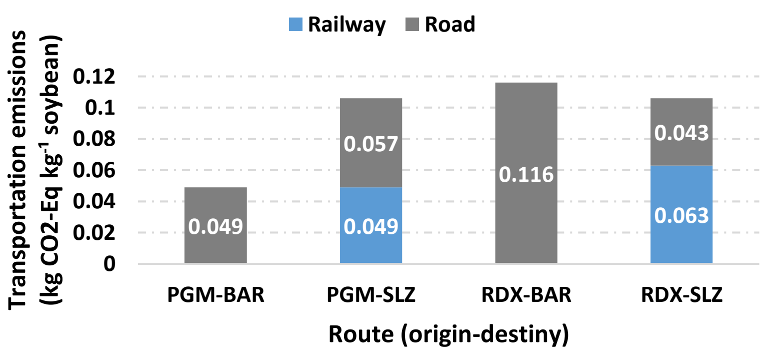

Figure 2. Climate change (GWP 20a) emissions from soybean transportation using IPCC 2013.

Table 4 shows land use transitions and their corresponding estimated CO2 emissions for three possible scenarios associated to the soybean cropping, according to BRLUC proposed [13], considering the carbon-foot print standard amortization along 20 years in the state of Pará.

Table 4. LUC and estimated scenarios of CO2 emissions between 1999 and 2018 in the state of Pará.

Soybean Crop expansion (%)	Scenarios	Emissions (tCO_2 Eq.$ha^{-1}.yr^{-1}$)	T0 soy (ha), Pre existent 1999	T1 soy (ha), 1st season 2018	Arable	Permanent crops	Unspecified, natural
	Min.	3,8	1 238	545 227	455 187 (84%)	38 523 (7%)	50 279 (9%)
100	Pro.	30,35	1 238	545 227	36 811 (7%)	3 115 (1%)	504 063 (92%)
	Max.	32,69	1 238	545 227	-	-	543 989 (100%)

Source: adapted from [13].

4. Discussion

Considering all the impact categories, the production system (agricultural phase) had the greatest contribution (hotspot) in eight of them: ALOP, GWP100, FETPinf, FEP, METPinf, MEP, TAP100 and TETPinf due to the sum of the inputs used in this stage, besides the operations that took place. However, the GWP100 are close to those reported by [1], with the production system responsible for 43.8% of this impact category. This is due two existing flows at this stage, which converges strictly as emissions to air: carbon dioxide fossil and dinitrogen monoxide (N_2O).

Despite the larger distance, the soybean transported from the Redenção pole converges better to São Luis due to the lower CO2 release from rail transport. [16] also reported lower CO2 emissions from grains transported by train compared transport by lorry. In addition, each wagon can carry 92.5 tonnes, and a company train on this line has up to 80 wagons each, and can ship up to 7 400 tonnes. However, a truck can only transport between 32 and 50 tonnes. The soy produced at the Paragominas pole converges better to the Barcarena because it is relatively closer and hence emits less pollutant.

The Amazon biome has the highest carbon stocks rate per hectare in Brazil. In addition, in the past 20 years, Pará has become a new agricultural frontier, and the transition from tropical forest (unspecified, natural) to the use of arable land with expansion of soybean crops may be associated with high CO2 emissions [13]. [13, 17] recommend that in LCA studies, emissions related to LUC should be described separately from the remaining data.

The LUC methodology considers only the deforestation made in the last 20 years, which somewhat penalizes agricultural supply chains located in new agricultural frontiers, such as the case of the Northern region in Brazil [13, 17]. According to the same author, several efforts have been made toward a low carbon agriculture. [5] highlighted that after soy moratorium, the majority of expansion of soy cultivation in amazon biome were allocated in already cleared areas.

Only 1.9% of the soybean crop area in the Pará State was allocated to deforested areas after July 22 of 2008. This is due to the soy moratorium, which aims to ensure that the soy produced and sold in the Amazon biome is not associated with deforestation of rainforest [18].

5. Conclusions

For the simulations done with the Recipe Midpoint (H), the production system was the main hotspot in the most of categories. We suggest that the train modal should be promoted, namely the expansion of the existing infrastructure and creation of a railroad between the producing regions and Barcarena since this modal can transport large loads more efficiently emitting less GHG to the atmosphere.

Regarding climate change, the LUC represents a significant contribution due the soybean cultivation is located in a new agricultural frontier, which had a great and recent expansion occurred in the last 20 years. Notwithstanding, this study was the first to apply the LCA method to the soybean supply chain in the state of Pará. It can serve as a starting point forward to new research that seeks to deepen the knowledge of LCA in soybean produced in this significant region of Brazil.

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References

1. Castanheira, E.G.; Freire, F. Greenhouse gas assessment of soybean production: Implications of land use change and different cultivation systems. *J. Clean. Prod.* **2013**, *54*, 49-60. <https://doi.org/10.1016/j.jclepro.2013.05.026>
2. USDA - United States Department of Agriculture, 2021. Foreign Agricultural Service. World Agricultural Production, Circular Series, WAP 4-21. Available online: http://apps.fas.usda.gov/psdonline/circulars/production.pdf (accessed on 15 April 2021).
3. CONAB – Companhia Nacional de Abastecimento. Acomp. safra bras. grãos, v. 7 - Safra 2019/20 - Nono levantamento, Brasília, p. 1-66, junho 2020. ISSN 2318-6852. Available online: <http://www.conab.gov.br> (accessed on 29 03 2021).
4. CONAB – Companhia Nacional de Abastecimento. Séries históricas das safras - Soja. Available online: <https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=30> (accessed on 29 03 2021).
5. Gibbs, H.K.; Rausch, L.; Munger, J.; Schelly, I.; Morton, D.C.; Noojipady, P.; Soares-Filho, B.; Barreto, P.; Micol, L.; Walker, N.F. Brazil's Soy Moratorium. *Science*. **2015**, 347, 377–378. <https://doi.org/10.1126/science.aaa0181>
6. Maciel, V.G.; Zortea, R.B.; Grillo, I.B.; Lie Ugaya, C.M.; Einloft, S.; Seferin, M. Greenhouse gases assessment of soybean cultivation steps in southern Brazil. *J. Clean. Prod*. **2016**, 131, 747–753. <https://doi.org/10.1016/j.jclepro.2016.04.100>
7. Matsuura, M.I.S.F.; Dias, F.R.T.; Picoli, J.F.; Lucas, K.R.G.; de Castro, C.; Hirakuri, M.H. Life-cycle assessment of the soybean-sunflower production system in the Brazilian Cerrado. *Int. J. Life Cycle Assess*. **2017**, 22, 492–501. <https://doi.org/10.1007/s11367-016-1089-6>
8. Environmental management – life cycle assessment – principles and framework (ISO 14040); ISO: Geneva, Switzerland, 2006.
9. Raucci, G.S.; Moreira, C.S.; Alves, P.A.; Mello, F.F.C.; Frazão, L.D.A.; Cerri, C.E.P.; Cerri, C.C. Greenhouse gas assessment of Brazilian soybean production: A case study of Mato Grosso State. *J. Clean. Prod*. **2015**, 96, 418–425. <https://doi.org/10.1016/j.jclepro.2014.02.064>
10. Cavalett, O.; Ortega, E. Integrated environmental assessment of biodiesel production from soybean in Brazil. *J. Clean. Prod*. **2010**, 18, 55–70. <https://doi.org/10.1016/j.jclepro.2009.09.008>
11. INMET – Instituto Nacional de Meteorologia. Meteorological Database of INMET. Available online: <https://bdmep.inmet.gov.br/> (accessed on 29 March 2021).
12. Environmental management – life cycle assessment – requirements and guidelines (ISO 14044); ISO: Geneva, Switzerland, 2006.
13. Novaes R.M.L.; Pazianotto, R.A.A.; Brandão, M.; Alves, B.J.R.; May, A.; Folegatti-Matsuura, M.I.S. Estimating 20-year land use change and derived CO2 emissions associated with crops, pasture and forestry in Brazil and each of its 27 states. *Glob Change Biol*. **2017**, 23, 3716–3728. <https://doi.org/10.1111/gcb.13708>
14. Faist Emmenegger, M;, Reinhard, J.; Zah, R. Sustainability Quick Check for Biofuels – intermediate background report. With contributions from T. Ziep, R. Weichbrodt, Prof. Dr. V. Wohlgemuth, FHTW Berlin and A. Roches, R. Freiermuth Knuchel, Dr. G. Gaillard, (Agroscope Reckenholz-Tänikon, Dübendorf, Switzerland). 2009.
15. Nemecek, T.; Schnetzer, J. Methods of assessment of direct field emissions for LCIs of agricultural production systems, Data v3.0, (Agroscope Recknholz-Tänikon Research Station ART, Zurich, Switzerland). Personal communication, 2012.
16. Silva, V.P., van der Werf, H.M.G., Spies, A., Soares, S.R. Variability in environmental impacts of Brazilian soybean according to crop production and transport scenarios. *J. Environ. Manage*. **2010**, 91, 1831–1839. <https://doi.org/10.1016/j.jenvman.2010.04.001>
17. Cederberg, C.; Henriksson, M; Berglund, M. An LCA researcher's wish list - data and emission models need to improve LCA studies of animal production. *Animal*, 2013, 7, 212–219. <https://doi.org/10.1017/S1751731113000785>
18. ABIOVE – Associação Brasileira das Indústrias de Óleos Vegetais, 2020. Soy Moratorium – 12th year report, Cropping 2018/19. Available online: <https://www.abiove.org.br/relatorios/moratoria-da-soja-relatorio-12o-ano/> (accessed on 15 April 2021).