Fakulta zemědělská a technologická
Faculty of Agriculture and Technology
Jihočeská univerzita v Českých Budějovicích
University of South Bohemia in České Budějovice

UNIVERSITY OF SOUTH BOHEMIA IN ČESKÉ BUDĚJOVICE
FACULTY OF AGRICULTURE AND TECHNOLOGY

Department of Agroecosystems

Master's Thesis

Evaluation of Environmental Impacts of Selected Crop (Soybean) using the LCA Method: withfocus on the Impact Category of climate change

Author: Nnando Emeka Micheal
Supervisor: Jiří Lehejček, Ph.D.
Consultant: doc. Ing. Jan Moudry, Ph.D.

České Budějovice
2024

Declaration
I declare that I am the author of this thesis and that I have elaborated it only with the use of sources and literature listed in the list of sources used.

In České Budějovice on 20th April 2024 ....

Signature

Abstraktní

Důsledky intenzifikace zemědělství a konvenčního zemědělství jsou stále zjevnější, protože změna klimatu a proměnlivost se stále zhoršují. Tato studie hodnotila dopady produkce sóji na životní prostředí se zaměřením na kategorii dopadu změny klimatu. Zemědělská data pro různé vstupy, agrotechnické operace a výstupy výrobního procesu byla systematicky sbírána ze tří odlišných farem sóji (Becicka, Michalec a Agrokiwi) v okrese Pardubice v České republice a analyzována pomocí rámce Life Cycle Assessment (LCA). Funkční jednotkou uvažovanou v této studii byl 1 kg sójových bobů. Výsledky LCA ukazují, že farmy Agrokiwi a Michalec mají největší a nejmenší příspěvek do kategorie dopadu změny klimatu s 6,17 kg CO2 ekv. a 2,1 kg CO2 ekv. Nejvyšší příspěvek, 51 procent, z Agrokiwi byl přisouzen aplikaci hnojiva NPK (15-15-15) a orbě polí, s 0,0506 kg CO2eq a 0,0237 kg CO2eq, zatímco setí a doprava přispěly nejméně, s 0,00979 kg CO2ekv a 0,0091 kg CO2ekv. Zjištění také odhalila vztah mezi vstupy, agrotechnickými operacemi při produkci sóji a jejich příspěvkem ke změně klimatu. Pokud jde o klimatickou chytrost nebo udržitelnost životního prostředí, je zemědělský postup/výrobní systém Michalec šetrnější k životnímu prostředí díky nízkému používání minerálních hnojiv a rozmetání. Výsledky studie naznačují, že environmentální výkonnost produkce sóji by se mohla výrazně zlepšit přechodem od syntetických hnojiv k ekologičtějšímu ekologickému zemědělství, zavedením střídání plodin a používáním odrůd semen odolných vůči chorobám jako prostředku implementace udržitelných zemědělských postupů. /systémy**.**

Klíčová slova: Vliv na životní prostředí, změna klimatu, LCA, sója

Abstract

The consequences of agricultural intensification and conventional farming are becoming increasingly apparent as climate change and variability continue to worsen. This study evaluated the environmental impacts of soybean production, with a focus on the climate change impact category. Agricultural data for various inputs, agrotechnical operations, and outputs of the production process were systematically collected from three distinct soybean farms (Becicka, Michalec and Agrokiwi) in the Pardubice district of the Czech Republic and analyzed using the Life Cycle Assessment (LCA) framework. The functional unit considered in this study was 1 kg of soybeans. The results of the LCA show that the Agrokiwi and Michalec farms make the largest and smallest contributions to the climate change impact category with 6.17 kg CO2eq and 2.1 kg CO2eq respectively. The highest contribution, 51 percent, from Agrokiwi was attributed to the application of NPK fertilizer (15-15-15) and tillage plowing of the fields, with 0.0506 kg CO2eq and 0.0237 kg CO2eq respectively, while sowing and transport contributed the least, with 0.00979 kg CO2eq and 0.0091 kg CO2eq respectively. Findings also revealed a relationship between inputs, agrotechnical operations in soybean production, and their contribution to climate change.Regarding climate smartness or environmental sustainability, the Michalec agricultural practices/production system is more environmentally friendly due to the low use of mineral fertilizers and the spreading method.The results of the study suggest that the environmental performance of soybean production could be significantly improved by switching from synthetic fertilizers to more environmentally friendly organic farming, introducing crop rotations, and using disease-resistant seed varieties as a means of implementing sustainable agricultural practices/systems.

Keywords: Environmental impact, Climate Change, LCA, Soybean

Acknowledgment

My profound gratitude goes to the almighty God who made this journey, and this work a success. I would like to thank my supervisors, Dr. Jiří Lehejček, Ph.D., and Doc. Ing. Jan Moudrý, Ph.D., whose help and guidance made this work a success. A big thank you also goes to Mr. Pavel and Emmanuel Mukosha, who supported and relieved me in data collection and LCA analysis.

To my coordinator for international students at the faculty, Karla Dvořáková, thank you for your support from admission processing to enrollment and visa renewal - I am glad to have you as my international relations officer. To my brother from another mother, Mr. Adeshina Ayodele, also known as Bobby, thank you for your support and kind gestures throughout this programme. To all my course mates: It was a pleasure spending this time with you and learning from you all.

I cannot thank enough my spiritual parents, Prophet E.k Obadara and Pastor Mrs. Obawunmi, and my boss turned brother, Engr. Taiwo Ogunlola, thanks for the prayer times despite how inconvinient it seems to be sometimes. My special thanks to my dearest friends, Ifeanyi Victor and Fransisca Ndukwe, who not only believed in me but also sowed the seed that set this journey of my studies in Europe in motion.

To my dear paternal mother, Mrs. Ngbanwa Benedicta, thank you for laying the foundation for my university education. Special thanks to my siblings Akinwunmi Akeem and Onyebuchi Badmus for always believing in me. To my cousin, Bello Ebi, thanks for the last-minute contribution before I left for Europe. To my roommate, Dr. Usman A., I thank you for your motivation and support, especially in difficult times.

And to everyone who has helped make this adventurous journey worthwhile, even if the list seems endless, you are all appreciated. Thank you for your love and care.

.

CONTENT

Introduction

As the global population continues to grow rapidly, intensifying agricultural practices emerges as a pivotal strategy to address the escalating demands for food and agro-allied resources. However, amidst this pursuit of increased productivity, the imperative of environmental sustainability looms large.

It is paramount to ensure that agricultural endeavors do not jeopardize environmental integrity or compromise long-term sustainability, particularly concerning input materials, energy utilization, and the accompanying environmental burdens, notably greenhouse gas emissions, that accompany such systems. These emissions, including CO_2, N_2O, and CH_4 gases, alongside other pollutants, significantly contribute to climate change, a pressing global issue characterized by escalating temperatures, erratic precipitation patterns, and heightened weather variability.

Agricultural activities stand prominently among the contributors to atmospheric pollution, underscoring the urgency for mitigative measures. An effective response to climate change necessitates comprehensive assessments of agricultural systems and processes, coupled with the adoption of climate-smart and ecologically sound farming practices.

The utilization of Life Cycle Assessment (LCA) methodology emerges as a potent tool in assessing the environmental ramifications across all stages of agricultural systems, from production to consumption. The structured framework of LCA facilitates the quantification of input utilization, output evaluation, and, crucially, the assessment of environmental stressors posed by agricultural operations.

Insights gleaned from LCA analyses offer valuable guidance in the development and implementation of sustainable agricultural practices that not only enhance productivity but also mitigate environmental impacts, particularly those associated with climate change.

As the global community strives to address the challenges of food security and environmental preservation, integrating LCA methodologies shows promise in promoting a resilient and environmentally conscious agricultural sector.

1 Literary Review

1.1 Impacts of Agriculture on the Environment

Growing demands on agricultural land for food, fiber, and fuel are predicted to rapidly increase in the coming decades with continued population growth (Bommarco et al., 2013). This demand equally calls for the intensification of farming and other agro-processing activities. However, it is important to note that agriculture can either sustain or degrade the environment. The (Millennium Ecosystem Assessment, 2005) described agriculture's main negative effects on land and freshwater, as well as the importance of agricultural landscapes in providing products for human sustenance, supporting biodiversity, and maintaining ecosystem services.

According to (Rohila et al., 2017), environmental impacts are the result of the intensification of agriculture, which signifies unsustainable resource use and the use of modern inputs such as chemicals and machinery. Water, soil, air, and biodiversity are common domains for all agricultural practices, and any environmental impact resulting from agriculture would be reflected in these domains. Thus, environmental impacts arising from agriculture are presented under these domains of impact (Air, Biodiversity, Soil, and Water). These environmental impacts will differ based on the farm location, farm type, specific farming and land management practices used, as well as the timing of these practices (i.e., the season of fertilizer application). For instance, nutrients and pesticides can run off agricultural fields into surface water bodies or leach into groundwater. Increased phosphorus loading from agriculture is one of several factors that have resulted in algal blooms in both Lake Erie and Lake Winnipeg (Michalak et al., 2013; Schindler et al., 2012).

Negative impacts, such as the conversion of forests, grasslands, and other habitats for agricultural use, degradation of soil quality (20 per cent of African soils are seriously degraded), pollution of soil and surface water, aquifers, and coastal wetlands through excessive or inappropriate use of pesticides and fertilizers, significant loss of crop and livestock genetic diversity through the spread of industrial monoculture, reducing resilience in the face of climate and other changes (Rohila et al., 2017).

The scientific community believes that agricultural production, particularly animal production, contributes significantly to greenhouse gas emissions and is resolved to safeguarding the environment by reducing emissions.

The agriculture production is one of the significant contributors to the emission of Greenhouse gases (GHGs), soil degradation, biodiversity losses, and contamination and consequently both a contributor and a casualty to environmental change. As indicated by IPCC, the Agriculture sector accounts for around 24% of complete GHGs discharge.

However, at the same time, the food demand of the growing world population's food demand must be met in both quantity and quality. It was found that "8.9 % of the world population is hungry, and food security challenges will only turn out to be more difficult, as the need might arise to create around 70% more food by 2050 to take care of an expected 9 billion individuals" (FAO, 2020). Therefore, it is vital to fulfill the world's food need by working on agricultural production alongside assessing the impact of agricultural production on the climate (Lobb et al., 2016). The UNEP's 2021 report "Making Peace with Nature" considers Agriculture sectors as an industry that is both a driver and danger from environmental degradation.

The impact of agriculture production on the environment can be evaluated through two approaches:

Based on agricultural production methods

Based on the impact that agricultural methods have on the environment.

1.2 Based on agricultural production methods.

1.2.1 Animal Agriculture: The effect of animal agriculture fluctuates with the various techniques/practices utilized universally, yet all agrarian practices affect the environment. The impact of animal agriculture is extremely huge, particularly meat production, which includes land use, contamination, diseases, biodiversity loss, GHGs Emission, food and water debasement and so on (Naujokiené et al., 2021).

Lately, industry, energy production, utilization, the expansion in how much waste connected with farming animals, and the adjustment of how much methane have made us deal with the issue of global warming (Kiliç and Boga, 2021; Philipps et al., 2022).

Methane (CH_4) is the second global warming gas, accounting for 20% of worldwide discharges. Carbon dioxide (CO_2), nitrogen oxide (N_2O), and chlorofluorocarbon (CFC) gases are the principal GHG.

The agricultural sector has a huge wellspring of CH_4, and animal compost is a significant wellspring of emissions (Calvet et al., 2017; Varma et al., 2021; Rosa et al. 2022). Oblivious agriculture and domesticated animals' practices cause an expansion in the outflow of GHG like CO_2, CH_4, and N_2O. Furthermore, through the creation of CH_4 and N_2O dairy cattle are the principal sources of GHG outflows from agriculture.

Worldwide, animal production creates roughly 5.6-7.5 Gt of CO_2 each year. Intestinal aging is answerable for around 2 Gt of CO_2 each year (Grossi et al., 2019). Animals' compost is a source of CH_4 and N_2O, two intense outflows with a 100-year global warming potential, 34 and 298 times stronger than CO_2. The worldwide worth of CH_4 is obscure, and there is no broad exploration including the contribution of animals (Chang et al., 2019; Lunt, et al., 2019). It has been expressed that CH_4 delivered from animals by enteric fermentation constitutes around 25% of the worldwide anthropogenic CH_4 outflow, and this rate increments by around 50% in provincial regions (Jafari et al., 2019). GHG like methane, carbon dioxide (CO_2), ozone gas (O_3), and nitrous oxide (N_2O) environmental change and cause global warming boost with infrared radiation in the environment (Nawab et al., 2020).

1.2.2 Irrigation: This connects with the degradation of Soil and water quality and quantity, which hence changes the hydrological state of water bodies. Another serious issue related to irrigation is over-irrigation and under-irrigation, which leads to water contamination. These issues can be easily controlled with uniform distribution and the management of wastewater. Under-irrigation increases harmful salts on the outer layer, which may harm the soil structure due to the formation of soluble soil (Amit et al., 2023).

1.2.3 Pesticides: Pesticides are toxic chemicals intended to kill pests, often affecting non-targeted species. Since the methods used involve spraying them across the entire agricultural land, 95-98% reach non-targeted objectives, negatively affecting the environment. Through spillover and pesticide drift, these chemicals often travel through various ecosystems, including marine environments, grazing fields, and more. In addition to these, production mismanagement, transport, and storage also adversely affect the environment (Amit et al., 2023).

1.2.4 Plasticulture: Plasticulture, which implies the utilization of plastic in agricultural applications, including soil fumigation films, plastic lines, tapes, covers, and so on.

These plastics are debased by synthetic substances during agrarian activities, making reusing these plastics extremely challenging. These plastics pollute the soil and, when degraded into microplastics, unfavorably harm the soil health and valuable microorganisms of the soil. Its impact on food is yet unclear, yet in light of different effects, many European nations have prohibited these plastics under the Circular economy action plan and are in the process of regulating their usage and waste in agricultural fields (Amit et al., 2023).

1.3 Based on the impact that agricultural methods have on the system:

1.3.1 Greenhouse gas Emission: Environmental change is mainly due to GHGs emission and the conversion of forests into agricultural land. Alongside being significant producers of GHGs, agriculture is also a significant user of petroleum derivatives and land through different agrarian production techniques and animal production. Anthropogenic sources, for example, energy use in agriculture and the management of agricultural land, are viewed as the major sources of GHGs discharge in agriculture production (Amit et al., 2023).

1.3.2 Pollutants: This refers to both biotic and abiotic byproducts of agricultural practices that contaminate and degrade the environment, resulting in harm to humans and its benefits (Amit et al., 2023). These pollutants include nutrients, microbes, pesticides, metals, sediments, and when these toxins enter the environment, they can affect the environment, which includes killing nearby habitats, contaminating soil and water, causing dead zones, and so forth. The effect of contaminations on the environment to a great extent relies on the management practices and strategies at different levels, such as agricultural operations, animal management, pesticide and fertilizer use, and waste management. "Air contamination caused through land use changes and animal farming practices can affect environmental change": IPCC special report on climate change and land (Raya et al., 2018).

1.3.3 Soil degradation: Soil degradation can be due to many factors, especially agriculture, which can be in the form of salting, synthetic pollution, decreased soil structure quality, disintegration, waterlogging, and changes in fertility, acidity, and alkalinity of the soil.

This also influences the microbial community of the soil and changes the nutrient cycle and chemical transformation property, water-holding capacity, and so on.

1.3.4Tillage erosion: There are confirmations that on sloppy and uneven sites, tillage erosion is a significant soil erosion process, surpassing wind and water erosion. Cultivation erosion results in soil degradation, leading to reduced crop yield and, consequently, financial losses for the farm.

1.4 Systems of Farming

1.4.1 Organic farming

According to the definition by the United States Department of Agriculture (USDA), the term organic farming refers to "a framework which evades and to a great extent rejects the utilization of artificial inputs" (e.g., fertilizers, pesticides, chemicals, feed additives, and so on.). Organic farming depends upon crop rotations, crop buildups, animal composts, off-farm organic waste, mineral-grade rock additives, and biological systems of nutrient mobilization, guaranteeing plant protection optimally. Organic agriculture is a production system that sustains the health of soils, ecosystems, and people. It depends on ecological processes, biodiversity, and cycles adjusted to local circumstances, rather than the utilization of inputs with adverse impacts. Organic agriculture combines tradition, innovation, and science to help the common environment and advance fair relationships and great personal satisfaction for all involved (Organic Farming | NRCS. (n.d.).

1.4.2 Conventional Farming

Conventional agriculture is used in the discursive construction of the case for alternative approaches to agriculture (i.e., alternative to conventional agriculture) (Giller et al., 2017). When used in this way, conventional agriculture, like the term industrial agriculture, often carries with it a set of implicit assumptions or explicit associations (Rosati et al., 2020). These include being innately unsustainable, environmentally destructive, greenhouse gas-producing, highly mechanized, large-scale, dominated by corporate interests, bad for rural communities, unaccountable, and so on. These associations can be particularly important in the discursive construction of the case for radical or ‘transformative’ change.

1.5 Greenhouse Gas Emissions - Overview and Agriculture

1.5.1 What Are Greenhouse Gas Emissions

The release of greenhouse gases, linked to human activities and climate change, is referred to as greenhouse gas emissions or environmental pollution. Since the beginning of the Industrial Revolution and the advent of coal-powered steam engines, human activities have significantly increased the volume of greenhouse gases released into the atmosphere. It is estimated that between 1750 and 2019, atmospheric concentrations of carbon dioxide increased by 47%, methane by 156%, and nitrous oxide by 23% (IPCC, 2021). In the late 1920s, man-made fluorinated gases like chlorofluorocarbons were introduced. Of all human-driven emissions of carbon dioxide, approximately half were generated in the last 30 years alone (Thorfinn et al., 2022). While global greenhouse gas emissions have occasionally leveled or declined from year to year (most recently at the beginning of the Coronavirus pandemic, when reduced global travel and manufacturing decreased carbon dioxide emissions by almost 6%), they are accelerating once again (UN, 2021).

1.5.2 Carbon Dioxide: Carbon dioxide accounts for nearly 70% of global human-caused emissions. Carbon dioxide lingers in the atmosphere for a long time. After it is released into the air, 40% remains after 100 years, 20% after 1,000 years, and 10% for up to 10,000 years (EPA, 2023).

1.5.3 Methane: Methane (CH_4) persists in the atmosphere for up to 12 years, which is less than carbon dioxide, but it is significantly more potent in terms of the greenhouse effect. In fact, pound for pound, its global warming impact is almost 30 times greater than that of carbon dioxide over a 100-year period. In the US, methane accounted for over 12% of human-produced greenhouse gas emissions in 2021. In Europe, it contributed to 11% of greenhouse gas emissions (EEA, 2019).

While methane can originate from natural sources like wetlands, most of the global methane emissions result from human activities, such as natural gas production and livestock-based agriculture (Courtney Lindwall | NRDC, 2022).

1.5.4 Nitrous Oxide: Nitrous oxide (N_2O) is a potent greenhouse gas with a global warming potential approximately 270 times that of carbon dioxide, and it remains in the atmosphere for over a century (EPA, 2023).

It represents around 6% of human-caused greenhouse gas emissions in the US, stemming from sources like the fertilizers used in agriculture (Courtney Lindwall | NRDC, 2022). It constitutes 6% of greenhouse gas emissions in Europe due to pollution (EEA, 2019).

1.5.5 Fluorinated Gases: Fluorinated gases are man-made and emitted from various industrial and manufacturing processes. There are four main categories: hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), and nitrogen trifluoride (NF3) (Courtney Lindwall | NRDC, 2022). Although fluorinated gases are produced in smaller quantities than other greenhouse gases, they account for 3% of U.S. emissions and 2% of greenhouse gases in Europe due to pollution. Importantly, the global warming potential of these gases can be in the thousands to tens of thousands, and they have long atmospheric lifetimes, sometimes lasting tens of thousands of years. HFCs are used as replacements for ozone-depleting chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), primarily in air conditioners and refrigerators, although some are increasingly being phased out due to their high global warming potential. Replacing these HFCs and properly disposing of them is considered one of the most significant environmental steps the world can take (Courtney Lindwall | NRDC, 2022).

1.5.6 Water Vapor: The most abundant greenhouse gas overall, water vapor differs from other greenhouse gases in that changes in its atmospheric concentrations are linked not to human activities directly, but rather to the warming that results from other greenhouse gases. Warmer air holds more water, and since water vapor is a greenhouse gas, more water absorbs more heat, leading to even greater warming and perpetuating a positive feedback loop (Alan, 2022). Increased water vapor also enhances cloud cover, which reflects the sun's energy away from the Earth but holds heat in at night (Fred, 2020).

1.6 Agricultural Land Usage: A Source of GHG Emission

Empirical data shows that continuous and persistent greenhouse gas emissions (GHGs: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), etc.) into the atmosphere are the major cause of observed global warming events and the climate crisis.

GHGs are produced biologically or naturally (through the activity of specific microorganisms in soils or via chemical reactions) and by human activities (anthropogenic sources: energy sector (73.2%), industry (5.2%),
waste (3.2%)), with the remainder attributed to agriculture (crop production, rural soils, livestock), land use, and forests (USGCRP, 2017).

About one-quarter of global greenhouse gas emissions come from agriculture and other land uses, such as deforestation. In the US, agricultural activities, primarily livestock and crop cultivation for food, accounted for 10% of greenhouse gas emissions in 2021. Agriculture constituted 10.55% of Europe's greenhouse gas emissions in 2019 (EEA, 2019). Worldwide, total agriculture and related land use emissions reached 9.3 billion tons of carbon dioxide equivalent (Gt CO2eq). Crop and livestock activities within the farm gate generated more than half of this total (5.3 Gt CO2 eq), with land use and land use change activities responsible for nearly 4 Gt CO2 eq (FAO, 2018). Most of these emissions were methane, which is produced as manure decomposes and as meat and dairy cows belch and pass gas, and nitrous oxide, often generated by the use of nitrogen-heavy fertilizers. Trees, plants, and soil absorb carbon dioxide from the air. Plants and trees do so through photosynthesis (a process by which they convert carbon dioxide into sugars that plants need to grow), while soil harbors microorganisms that bind carbon.

Therefore, non-agricultural land use activities such as deforestation, reforestation (replanting in existing forested areas), and afforestation (creating new forested areas) can either increase the amount of carbon in the atmosphere (as in the case of deforestation) or reduce it through absorption, removing more carbon dioxide from the air than is emitted. When trees or plants are cut down, they no longer absorb carbon dioxide, and when they are burned as biomass or decompose, they release carbon dioxide back into the atmosphere. In the US, land use activities now represent a net carbon sink, absorbing more carbon dioxide from the air than they emit.

1.7 EPA Used Models to Estimate Greenhouse Gas Emissions

The Environmental Protection Agency (EPA) employed models to assess greenhouse gas emissions. Agriculture contributes to GHG emissions through crop and soil management, enteric fermentation in domestic livestock, and animal manure management.

Greenhouse gas emissions associated with the production and use of power occur within each of these activities.

Agriculture is estimated to have directly released 629 MMT of CO2e in 2019. When emissions related to electricity are allocated to economic sectors, agriculture released an additional 35 MMT CO2e, resulting in a total of 664 MMT of CO2e in 2019.

Carbon dioxide constituted approximately 1% of direct agriculture related GHG emissions. Nitrous oxide (N_2O) and methane (CH_4) are the primary greenhouse gases emitted by agricultural activities. Total nitrous oxide emissions from agriculture were 364 MMT CO2e, accounting for 58% of all agricultural CO2e in 2019.

In 2019, 28% of CO2e emissions in agriculture came from methane released during enteric fermentation. Another 10% of CO2e as methane was emitted from manure management. From 1990 to 2019, agricultural emissions increased by 13%, rising from 555 to 629 MMT of CO2e. Climatologists consider total emissions to be a critical metric driving climate change and are concerned that U.S. emissions have increased during this period. Reducing total emissions from agriculture requires either reducing greenhouse gas-emitting agricultural production or decreasing the amount of greenhouse gases released per unit of production, or both.

The trend of global population growth necessitates increasing agricultural output in the foreseeable future. Yield-scaled emissions, which measure how much GHG is released per unit of production, are calculated by dividing GHG emissions by units of industry output. Agricultural yield-scaled emissions have been decreasing. The USDA reports that total agricultural output increased by 31% from 1990 to 2017. GHG emissions per unit of total agricultural production decreased by 15% during the same period. The increase in total agricultural emissions has resulted from increased quantities of crops and livestock produced. The reduction in yield-scaled emissions has been the consequence of improved efficiencies.

1.7.1 Industry

Approximately one-fifth of global human-driven emissions come from the industrial sector, which includes the manufacturing of goods and raw materials (such as cement and steel), food processing, and construction. In 2021, industry accounted for 23% of U.S. human-made emissions, with the majority being carbon dioxide, though methane, nitrous oxide, and fluorinated gases were also emitted.

In 2019, industry constituted 9.10% of Europe's greenhouse gas emissions. According to the U.S. Energy Information Administration (2021), nearly a quarter (23 percent) of U.S. greenhouse gas emissions originate directly from industrial sources. These direct emissions result from various processes, including on-site fossil fuel combustion for heat and power, non-energy use of fossil fuels, and chemical processes used in iron, steel, and cement production. Additionally, industry generates indirect emissions from centrally generated electricity consumption.

The industrial sector accounted for about one-quarter of total U.S. electricity sales. When direct and indirect emissions are combined, the industrial sector is the largest emitting sector in the U.S. economy, responsible for 29.6% of total emissions.

1.7.2 Transportation

The combustion of petroleum-based fuels, especially gasoline and diesel, to power the world's transportation systems accounts for 14% of global greenhouse gas emissions. In the United States, transportation is the largest contributor of greenhouse gases, representing 28% of U.S. emissions in 2021. Carbon dioxide is the primary gas emitted, but fuel combustion also produces small amounts of methane and nitrous oxide. Vehicle cooling and refrigerated transport systems release fluorinated gases as well.

1.7.3 Buildings

The operation of buildings generates 6.4% of global greenhouse gas emissions. In the United States, homes and businesses are responsible for about 13% of greenhouse gas emissions. These emissions, primarily consisting of carbon dioxide and methane, primarily result from burning natural gas and oil for heating and cooking. Other sources include refrigerants (fluorinated gases) leaking from air-conditioning and refrigeration systems and the management of waste and wastewater.

These direct emissions do not include indirect emissions, such as those related to electricity usage for cooling, lighting, running appliances, and more, as well as emissions from building construction.

1.7.4 Other Sources

This category encompasses emissions from energy-related activities other than fossil fuel combustion, such as the extraction, refining, processing, and transportation of oil, gas, and coal. Globally, this sector accounts for 9.6% of emissions.

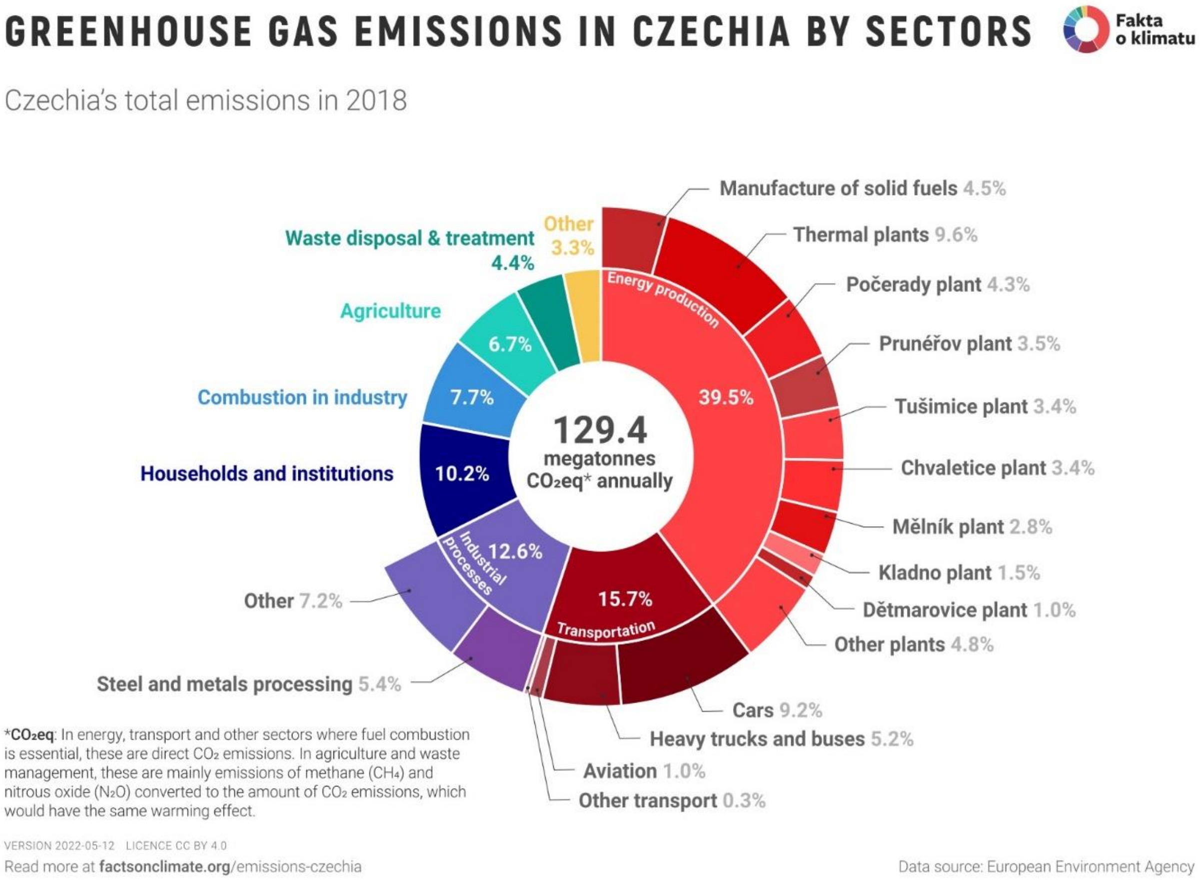

Figure 2.1: Greenhouse gas emissions by sectors in Czech Republic according to European Environmental Agency

1.8 Key Strategies for Reducing Greenhouse Gas Emissions and Climate Change Mitigation

1.8.1 Adopting improved nutrient management in agricultural lands: To achieve this, farmers should be educated through policies and extension services on various methods of nutrient utilization that limit nutrient loss contributing to emissions of gases like nitrous oxide (Huang et al. 2019).

A promising approach to reducing losses is by reducing nitrification. The use of nitrification inhibitors in nitrogen use is a promising strategy that can slow down processes contributing to N2O emissions (Coskun et al. 2017).

The utilization of advanced crop varieties with higher nitrogen uptake and utilization efficiencies will lead to reduced nutrient losses, as these crop genotypes fully utilize applied and available nutrients, resulting in fewer losses in the form of GHG emissions (Sanz-Cobena et al. 2017).

Improved nutrient management is considered a practical strategy for addressing the challenges associated with the impacts of climate change on crop and food security. According to García-Marco et al. (2016), adopting advanced agronomic practices can lead to better yields and promote the generation of more carbon that can be used to increase soil carbon storage, thereby reducing losses to the environment. Some practices recommended by García-Marco et al. (2016) include increasing crop rotation, using improved varieties as mentioned earlier in this text, and practicing mixed cropping with perennial crops, which results in more carbon storage in the soil. GHG emissions can also be reduced by implementing intensive cropping systems that reduce reliance on pesticides and other agricultural inputs, thus reducing emissions to the environment (Hoekman and Broch 2018). Furthermore, farmers can use cover crops that provide additional carbon to the soil and may assist in sequestering unused nitrogen for subsequent crops, resulting in reduced N2O emissions (Oberthür et al. 2019). The use of Global Positioning Systems (GPS) guidance and variable rate technology is helpful in applying inputs, allowing farmers to optimize nutrients and subsequently reduce GHG emissions. Additionally, the use of slow-release fertilizers, such as prilled urea, can be an effective approach to reducing N2O emissions from cropland. Moreover, the use of biofertilizers has been proposed as an alternative to more soluble and reactive nitrogen sources, as reported in excellent reviews by Ntinyari and Gweyi-Onyango (2018).

1.8.2 Proper Management of Residue and Adoption of Appropriate Tillage Methods

Utilizing effective techniques for weed control and machinery in farming systems is another approach to reduce N2O emissions from the soil. This is attributed to the fact that soil disturbances tend to accelerate soil carbon loss through increased erosion, which results in soil carbon depletion. However, the choice of tillage method depends on the soil's climatic conditions. Some reduced tillage options might have a significant impact on N2O emissions from cropland (Feng et al. 2018).

In tillage systems where farmers retain crop residues, they generally increase soil carbon since these residues act as precursors of soil organic matter, which is a significant carbon store in soils. Particularly in the case of paddy crop cultivation, it has been found that no-tillage practices significantly reduce methane (CH_4) emissions.

Furthermore, recycling of crop residues has been reported to prevent the release or deposition of aerosols and GHGs produced during burning (Feng et al. 2018).

1.8.3 Biomass Burning

Biomass burning is a known contributor to climate change as it releases significant amounts of methane. This practice is common in regions like Kano fields in Western Kenya, especially under rice production. Therefore, it is imperative to manage fires associated with biomass burning in agricultural fields. Reducing biomass burning will also help minimize emissions of hydrocarbons and reactive nitrogen compounds, which contribute to the formation of tropospheric ozone (Leng et al. 2019). This is because smoke comprises aerosols that can have either warming or cooling effects on the climate, thus directly or indirectly contributing to climate change. In this context, reducing the frequency or intensity of fires will enhance landscape carbon density in soil and biomass. To mitigate these emissions, controlling fire outbreaks is suggested, involving strategies such as reducing fuel load through vegetation management and burning biomass when CH_4 and N_2O emissions are minimal (Leng et al. 2019).

1.8.4 Crop Rotation

Crop rotation is advocated because it has yielded beneficial results by improving soil quality, with reported overall increases of as much as 50% in terms of natural carbon content in soils (Paustian et al. 2019).

This practice enhances resilience in cropping systems and helps mitigate the impacts of climate change, making it a valuable option for Sub-Saharan Africa, where it is already practiced on a recognizable scale.Through this approach, sequestering carbon for long-term storage from the atmosphere. In this regard, crop rotation offers the most effective solution for counteracting greenhouse gas emissions in the ecosystem. Additionally, more crops are obtained from cropping systems, reducing the direct impacts of environmental factors on food security.

1.8.5 Introduction of Carbon-Sequestering Grass Species

The introduction of improved grasses with high production levels or adaptations for increased carbon allocation to deeper roots holds great potential for increasing soil carbon (Yang et al. 2019).

For example, established grasses in savannas have been associated with increased rates of carbon accumulation, reducing emissions to the atmosphere. Planting legumes in grazing lands has also been linked to enhanced soil carbon storage and may reduce N2O emissions (Garnett et al. 2017).

1.8.6 Development of Flexible Technology-Forcing Regulations

Greenhouse gas emissions are pressing issues that need government regulation, especially in Sub-Saharan Africa, where governments have not allocated significant resources to controlling emissions due to limited income capacity. If these issues remain unaddressed at the grassroots level, most people are unlikely to take them as seriously as they are considered internationally (Inglesi-Lotz and Dogan 2018). Hence, there is a need for flexible regulations intended to drive technological development for the necessary changes. For example, in the case of manure use, countries should develop regulatory systems similar to those in the United States or other places to enhance fleet fuel efficiency (Nyamoga and Solberg 2019).

1.8.7 Integrated Farming Systems

Integrated farming systems are another method for reducing GHG emissions and combating climate change. These systems rely on core practices that have been implemented in certain regions within Sub-Saharan Africa, including Kenya and Uganda. The practices aim to increase the recycling of nutrients found in animal manure and crop residues, ensuring a reduction in the use of chemical fertilizers and a consequent improvement in GHG reduction from agricultural land (Stanton et al. 2018).

1.9 Barriers to Mitigating GHG Emissions and Climate Change

Several barriers hinder GHG emission mitigation and addressing climate change in Sub-Saharan Africa. Many farmers in the region are unaware of the bottom-line effects of climate change and the factors originating from their cropping-livestock systems. A significant number of farmers in Sub-Saharan Africa are unaware of the available low or high-cost alternatives.

There is limited on-the-ground focus to address the issue, and addressing climate change and GHG emissions more effectively should start at the grassroots level. Additionally, there is uncertainty about the feasibility of the available measures among leaders and climate change activists, which has hindered awareness efforts. There are complex interactions that farmers are unaware of, which may have consequences on the complexity of interaction when adopting practices to reduce GHG emissions from agriculture (Mehra et al. 2018). Some of the suggested alternatives may conflict with cultural norms in various communities in Sub-Saharan Africa.

For instance, manure management may be seen as a dirty practice in some communities or due to religious beliefs, making its management challenging. Most farmers may fear loss aversion and be resistant to investing in best practices recommended by regulators. Existing services struggle to meet the needs of farmers, creating uncertainty about the low-cost recommendations they receive. Moreover, government agencies are slow to clarify the role of extension officers and the extent to which they should conduct community seminars on fundamental issues such as climate change and GHG emissions (Allen et al. 2020).

1.10 Soybean

Soybean (Glycine max) is one of the most valuable, versatile, and nutritionally important legumes globally. It can be grown in a multitude of environments, using a variety of management practices, and for diverse end-user purposes. (Shea et.al. 2020). Soybean originated in East Asia and has been cultivated in China for millennia. It is estimated that the domestication event from wild soybean (Glycine soja) occurred during the Shang Dynasty, 1700–1100 B.C. (Hymowitz et al.1987).

In 2018, roughly 398 million tons of soybeans were produced worldwide, which accounted for 61% of overall oilseed production and 6% of the world’s arable land use (Goldsmith PD.,2008).

Soybeans are one of the most flexible crops in terms of production methods, geographical growing regions, and end use versatility. Therefore, there are multiple agronomic practices to consider when preparing a field for soybean production. While tillage and fertilization practices are common among producers, technique specifications can vary greatly due to preferences, environmental conditions, and cost.

Historically, mechanized, and non-mechanized tillage was considered a vital practice to maximize crop yield and value.

According to soyastats. 2018, the United States, Brazil, and Argentina constituted approximately 81% of international soybean production, producing 34, 32, and 15%, respectively. Soybean seed composition and its main components, meal and oil, are the driving forces behind crop production that has increased nearly 350% since 1987.

Soybean meal is intricately connected to the food supply through direct food consumption and indirect consumption as a large source of livestock feed. Soy oil provides great versatility with uses in food and beverage, wax, construction, cosmetics, plastics, and fuel.

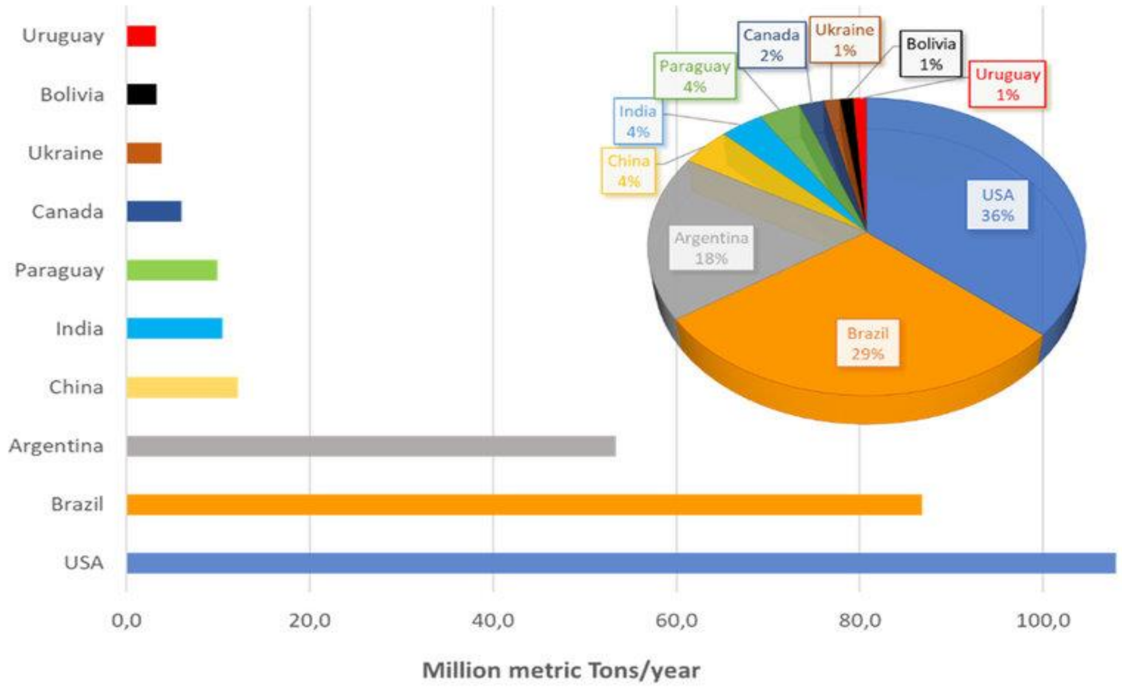

Figure 2.2. World Leader in Soybean Production. (FAOSTAT)

Figure 2.3: Soybean seed (worldatlas.com)

1.10.1 Plant Spacing and Sowing

Soybeans can be sown manually, with a planter, or by drilling. Plant 3 to 4 seeds per hole at a spacing of 75 cm between rows and 10 cm between plants. Alternatively, drill the seeds with spacing of 50-75 cm between rows and 5 cm within rows.

Early-maturing varieties respond better to narrow spacing, so a spacing of 50 cm between rows and 5-10 cm within rows is recommended for them. Do not plant seeds more than 2-5 cm deep, as deeper planting can lead to poor seedling emergence (Omiogui et al., 2020).

1.10. 2 Fertilization

Soybean fertilizer recommendations should be based on soil tests. Soybeans, as legumes, can fix nitrogen organically, but before nodulation, they rely on soil nitrogen. Phosphorus is often the most deficient nutrient. Apply phosphorus at a rate of 30 kg P per hectare as a single superphosphate fertilizer (SUPA), along with 2.5 bags of compound fertilizer NPK 15:15:15. Nitrogen and potassium fertilizers are only needed when clear deficiencies are observed. Incorporate the fertilizer into the soil during land preparation while harrowing and leveling the field (Omiogui et al., 2020).

1.10. 3 Soybean Harvesting

Soybeans mature within 3-4 months after planting and should be harvested in a timely manner to avoid excessive yield losses. When mature, the pods turn straw-colored.

Harvesting is recommended when about 85% of the pods have turned brown for non-shattering varieties or 80% for shattering varieties. Alternatively, the crop can be harvested when the seeds are in the hard-dough stage with a moisture content of 14-16%.

While modern varieties are less prone to shattering, delayed harvesting may still result in yield losses due to other factors. Harvesting can be done using a cutlass, hoe, or sickles. Cut the fully grown plants at ground level, stack them loosely, and allow them to dry in the open air for several weeks before threshing. Avoid harvesting by hand-pulling to prevent nutrient loss from the soil (Omiogui et al., 2020).

1.11 Impact of Soybean Cultivation on the Environment

The expansion of soybean production, driven by the increasing demand for protein and oil, has led to critical greenhouse gas (GHG) emissions due to land use changes associated with soybean cultivation. Soil organic matter is a crucial component of soil quality, affecting its properties, such as structure, buffering capacity, sorption capacity, air-water relationships, and thermal properties.

According to a study (Maciej et al., 2021) evaluating GHG emissions in soybean cultivation, biochar made from different crops can significantly reduce GHG emissions in agricultural production. Biochar was found to be effective in sequestering carbon in soils and increasing nutrient use efficiency by plants. Recent discussions about GHG emissions and the environmental impact of the agricultural sector, especially with the engagement of many countries in the Paris Protocol, have grown in significance. A study by (Vitória et al., 2022) aimed to understand how to calculate GHG emissions from soybean cultivation in Brazil. The study considered various methods of soil preparation and found that the most significant source of CO2 emissions in soybean production was the diesel used for harvesting machinery.

An analysis by (Esbati M., 2022) examined GHG emissions from Ontario soybean fields. Emissions from the manufacturing and transportation of nitrogen/phosphorus (N/P) fertilizer, field operations, herbicide use, and both direct and indirect emissions from agricultural lands were considered the major sources of GHGs. The results showed that total GHG emissions were approximately 7x105 Mg CO2-eq in 2018, with agricultural lands contributing 77% of the total emissions. GHG emissions were influenced by environmental conditions, with emissions decreasing as precipitation/evapotranspiration (Pr/PE) decreased from southern Ontario to central Ontario. The largest contributor to GHG emissions from agricultural lands was compost N inputs in southern and central Ontario.

Soybean biodiesel (B100) plays a significant role in the Brazilian energy sector's transition to a bio-based economy. A study by (CEP Cerri, 2017) assessed the GHG emissions of Brazilian soybean biodiesel production through a life cycle approach.

The results showed that agriculture was the largest source of GHG emissions for integrated systems, while production was the largest source for non-integrated systems. The integration of industrial units has resulted in a significant reduction in life cycle GHG emissions.

In a study by (EMM Esteves, 2018), integrated crop-livestock systems were compared to traditional soybean farming systems in terms of biodiesel production through a life-cycle assessment. This assessment considered both integrated and non-integrated production chains and found that the most significant factors impacting GHG emissions were crop rotation frequency and agricultural system management.

2 Aim of the Thesis

The aim of this study is to evaluate the environmental impacts of the cultivation of Soybean using Life Cycle Assessment (LCA) Method, with a focus on the impact category of climate change.

2.1 Study Hypothesis

Null Hypothesis (H_0): There is no significant relationship between inputs, agrotechnical operations in soybean production, and their contribution to climate change, as determined by the Life Cycle Assessment (LCA) method.

3 Materials and Methods

Soybean Production Data

Soybean production data spanning three consecutive years (2021-2023) were systematically gathered from three distinct soybean farms situated across various districts within the Pardubice of the Bohemia region, located in the eastern part of the Czech Republic. These farms encompass BECICKA (50°5′48″N 16°17′56″E) in Záměl, MICHALEC Běstovice 56 (49°9′38″N 16°14′5″E), and AGROKIWI (49°57′44″N 16°9′51″E) in Litomyšlská 58 Vysoké Mýto.

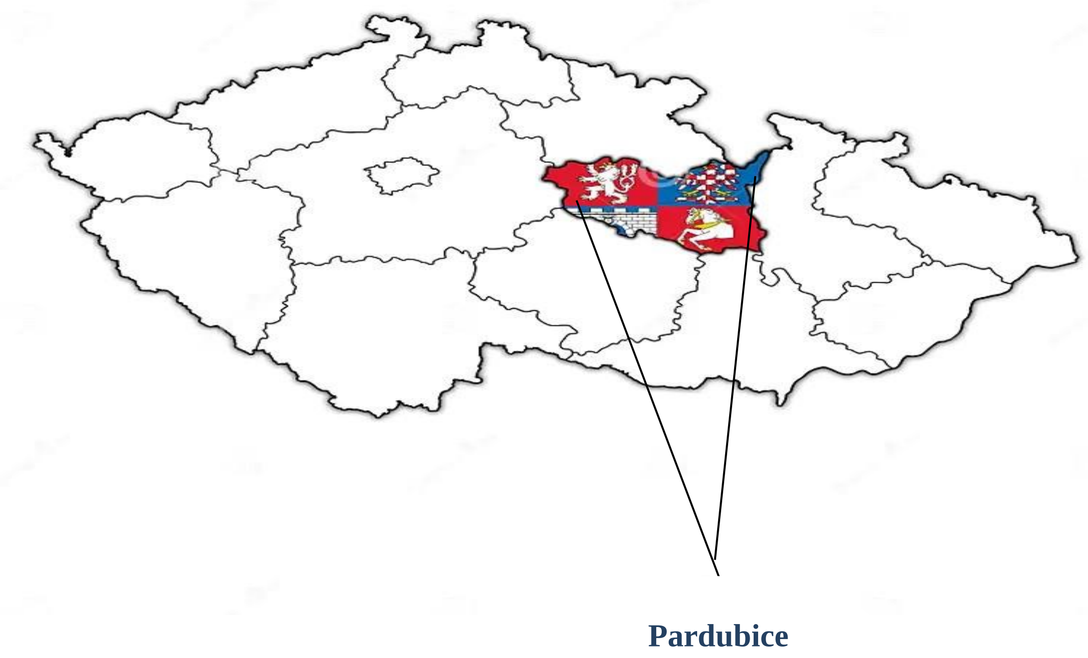

Figure 3.1: Study location on the map of the Czech Republic

Goal and Scope Definition

This study assessed the impacts soybean production on the environment using the agricultural LCA. A functional unit (FU) related to production (1kg of Soya bean) was chosen for this study. The system boundaries include all the processes from “cradle to farm gate”, i.e., crop production processes such as seed preparation, soil cultivation, sowing, fertilization, crop protection, transport of farming machinery, and harvesting. Associated emission with agrotechnical operations and Fertilization material are shown in the system boundaries as presented in Figure 1 below.

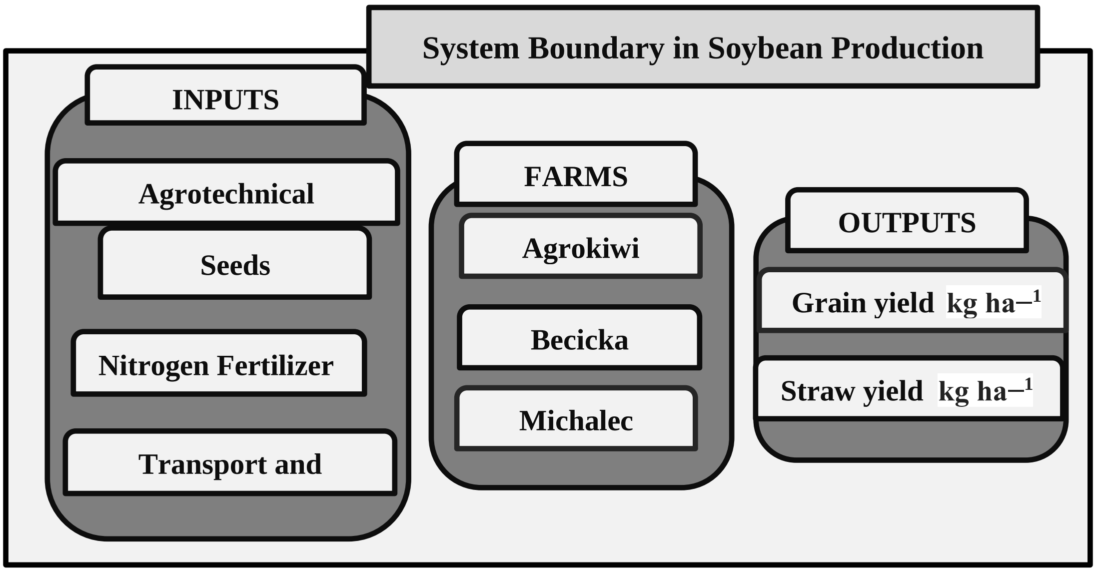

Figure 3.2: System Boundary in Soyabean Production

Life Cycle Assessment Framework

The LCA method used in this study is in accordance with ISO14044 (ISO,2006) and ISO14040 (ISO, 2006). This LCA includes four stages: Goal and scope definition, Life-cycle inventory, Life-cycle impact assessment and Data Interpretation as shown in Figure 2. SimaPro 9.5.0.1 software, ReCiPe Midpoint (H) V1.13/Europe Recipe H methodology, and data from Ecoinvent v3.5, WFLDB, and Agri-footprint v5.0, databases were used for assessment of the environmental aspect.

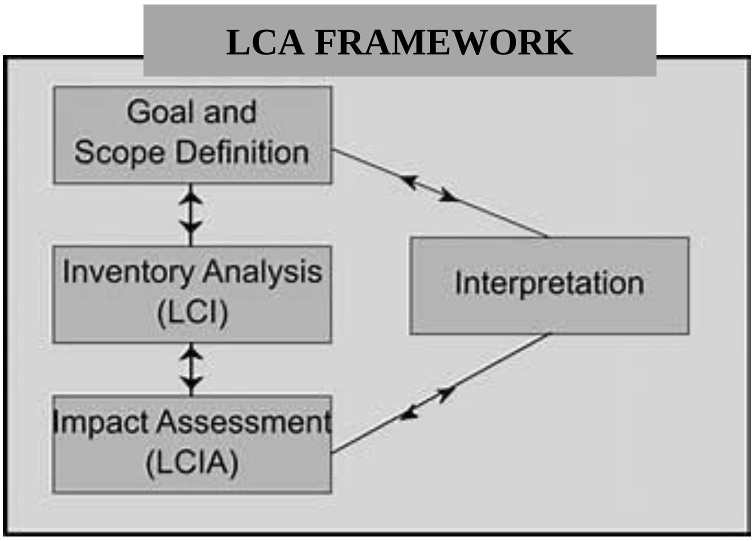

Figure 3.3: LCA Framework

Life Cycle Inventory (LCI) and Data Source

The primary data were obtained from Becicka, Michalec and Agrokiwi farms, and secondary data were obtained from background processes from Ecoinvent v3.8, which includes data from WFLDB, and Agri-footprint v5.0 databases (Van Paassen et.al, 2009). Table 1and 2 shows the inputs and outputs of the study from cradle to farm. The Intergovernmental Panel on Climate Change (IPCC) method was used to determine the emissions from fertilizers input.

1 Inputs and Outputs of the Life cycle

	Unit	Agrokiwi	Becicka	Michalec
Outputs				
Grain yield	kg ha^{-1}	2633	2533	3000
Straw yield	kg ha^{-1}	2000	2000	2500
Inputs from Technosphere				
Tillage, ploughing	ha	1	1	1
Tillage, by offset disc harrow	ha	1	1	1
Tillage, currying by weeder	ha	1	1	1
Sowing	ha	1	1	1
Fertilizing, by broadcaster	ha	1	1	2
Soybean Seed for sowing	kg	320	230	137
Plant protection, sprayer	ha	2	1	2
NPK compound (NPK 15-15-15)	kg ha^{-1}	-	100	100
Inorganic fertilizer calcium nitrate	kg	100	90	20
Herbicide, mix for soybean, at plant	kg	354	89	111
Herbicide emissions, at farm	kg	354	89	111
Combine Harvesting	ha	1	1	1
Transport, tractor, & trailer, agricultural	tkm	13.2	12.7	15
Resources				
Rain	m^3	634	634	634
Water (for diluting materials)	L	300	300	300

Table 3.1: Inventory table for input and output for the three soybean farms

Life Cycle Impact Assessment

A life cycle assessment method was used for environmental impact quantification. The data were analyzed and evaluated based on LCA standards ISO 14040 and ISO14044. The results of this study are related to the following impact categories: Climate change (global warming) (kg CO2 eq), terrestrial acidification (kgSO2 eq) and water depletion (m3). Selected impact categories are suitable for agricultural LCAs. The SimaPro 9.5.0.1 software was used to calculate the LCIA and impact category indicator. For this study, the ReCiPe Midpoint (H) V1.13/Europe Recipe H., an integrated method, was chosen. The ReCiPe method addresses environmental impacts at the midpoint level, which are further aggregated into end-point categories. For evaluation, the characterization approach was used. Overall, the environmental impacts of soybean production were compared between Becicka, Michalec and Agrokiwi farms.

4. Results

Results Agrotechnical operations in soybean cultivation for the farms

Based on the data received from the farms, several operations were carried out during the cultivation.

Agrokiwi: The results presented in Table 1 show that tillage, ploughing, sowing, weed control by currying, and fertilization with inorganic calcium nitrate (100 kg/ha) were all carried out once on average (1). The herbicide mixture for soybeans was sprayed twice (2), with an average of 354 kg of herbicides used in three cropping seasons. Precipitation as the main source of rainfall was recorded according to the annual average values of the Czech Republic (634 mm), with 300 m3 of water used to dilute the materials. For harvesting and transportation of grain and straw yields (2633 kg/ha and 2000 kg/ha) 13.2 tkm were covered.

Becicka: Table 1 above shows that tillage, plowing, sowing of soybeans (230 kg), weeding by harrowing and fertilization with NPK 15-15-15 (100 kg/ha) were carried out on average once (1). The herbicide mixture for soybeans was sprayed once (1), with an average of 89 kg of herbicides used in three cropping seasons. Precipitation, which is the main source of precipitation, was recorded according to the average annual precipitation data of the Czech Republic (634 mm), using 300 m3 of water to dilute the materials. For the harvesting and transportation of the grain and straw yields (2533 kg/ha and 2000 kg/ha), 12.7 tkm were covered.

Michalec: The results presented in Table 1 above show that tillage, plowing, sowing of soybean seeds (137 kg), weed control by currying and fertilization with NPK 15-15-15 (100 kg/ha) were carried out on average once (1). The herbicide mixture for soybeans was sprayed twice (2), with an average of 111 kg of herbicides used during the three growing seasons. Rainfall (634 mm) was recorded as the main source of precipitation according to the annual average values for the Czech Republic, with 300 m3 of water used to dilute the materials. 15 tkm was covered to harvest and transport the grain and straw yields (3000 kg/ha and 2500 kg/ha).

Impact Category	Damage Category	Abb.	Unit	Agrokiwi	Becicka	Michalec
Climate Change	Climate	GWP	kg CO2 eq	6.17	3.9	2.1
Terrestrial Acidification	Ecosystem Quality	TA	KgSO2 eq	0.0124	0.00753	0.104
Water Depletion	Resources	WD	m3	0.113	0.10 2	0.00428

Table 4.1: Midpoint environmental load per production unit (1 kg of soybeans)

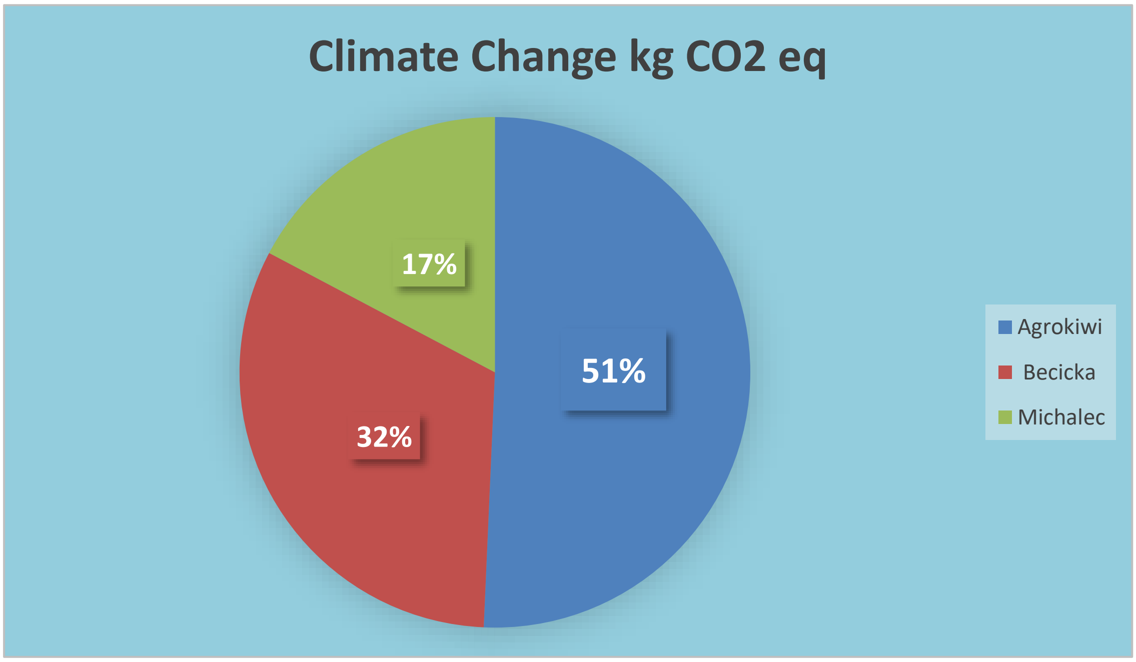

Figure 4.1: Percentage share of each farm's contribution to Climate change.

Climate change: The results show that soybean production in Agrokiwi farms has the highest environmental impact per production unit (1 kg of soybeans) in the mentioned impact categories, especially in the climate change category. With (kg CO_2 eq 6.17), the Agrokiwi farm has the largest contribution to climate change, accounting for 51% of the total contribution of the three farms. At Becicka and Michalec, the impact per production unit was (kg CO_2 eq 3.9) and (kg CO_2 eq 2.1) respectively, as shown in Table 3.

The Michalec farm has the lowest percentage contribution to climate change at 17%, as shown in a pie chart in Figure 4. The highest impact and highest percentage contribution of Agrokiwi farms can be linked to the high use of inorganic fertilizers and herbicides during soybean production.

This also shows a high contribution of fertilization as one of the agrotechnical operations carried out during soybean production. Fertilization at the rate of 100 kg ha^{-1} and 90 kg ha^{-1} in the Agrokiwi and Becicka farms, as shown in Table 1, is evidence of the high percentage contribution of soybean production to the climate change impact category.

Terrestrial acidification: The results presented in Table 3 show that the load per unit in the three farms contributes to terrestrial acidification, even if this category is not the focus of the study.

However, the contribution of Agrokiwi (KgSO_2 eq 0.0124), Becicka (KgSO_2 eq 0.00753) and Michalec (KgSO_2 eq 0.104) to terrestrial acidification is significantly low compared to climate change. This low contribution of the soybean production process to the acidification of the natural ecosystem can be seen because of the non-use of fertilizers with SO_2 compounds as the main component.

Water depletion: As shown in Table 3, each of the three farms contributed per unit of production (1 kg of soybeans) to the water depletion category. Agrokiwi was known to contribute the most (m^3 0.113), Becicka and Michalec had an environmental impact per unit of production of (m^3 0.102) and (m^3 0.00428) respectively.

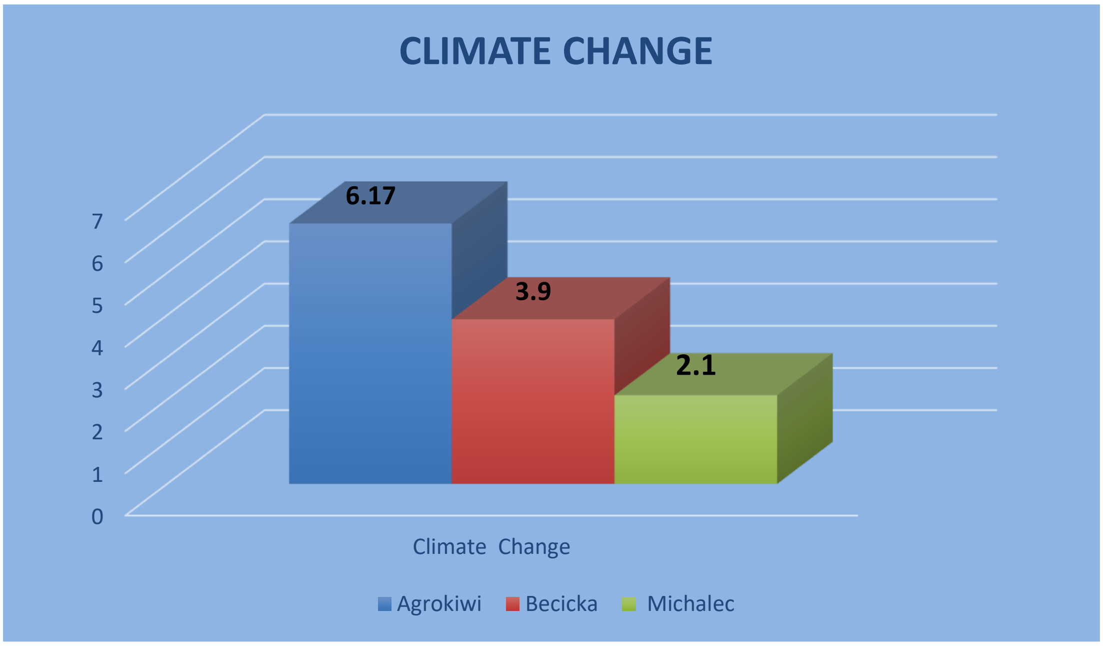

Figure 4.2: Graphical representation of impact category with climate change in the three farms.

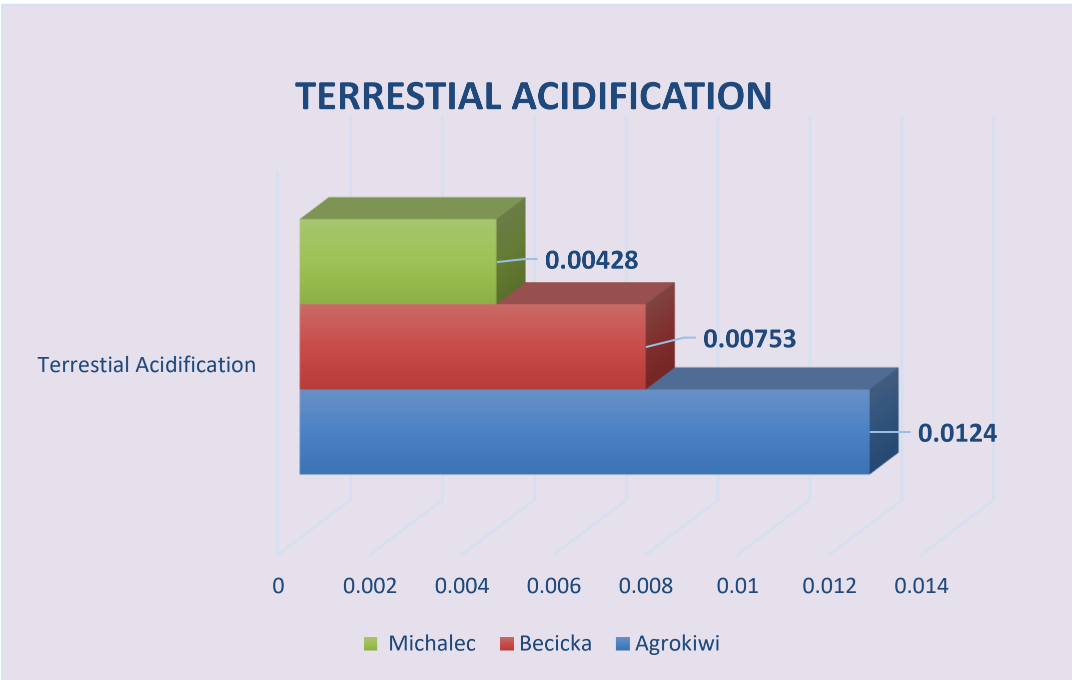

Figure 4.3: Graphical representation of impact category of Terrestrial Acidification.

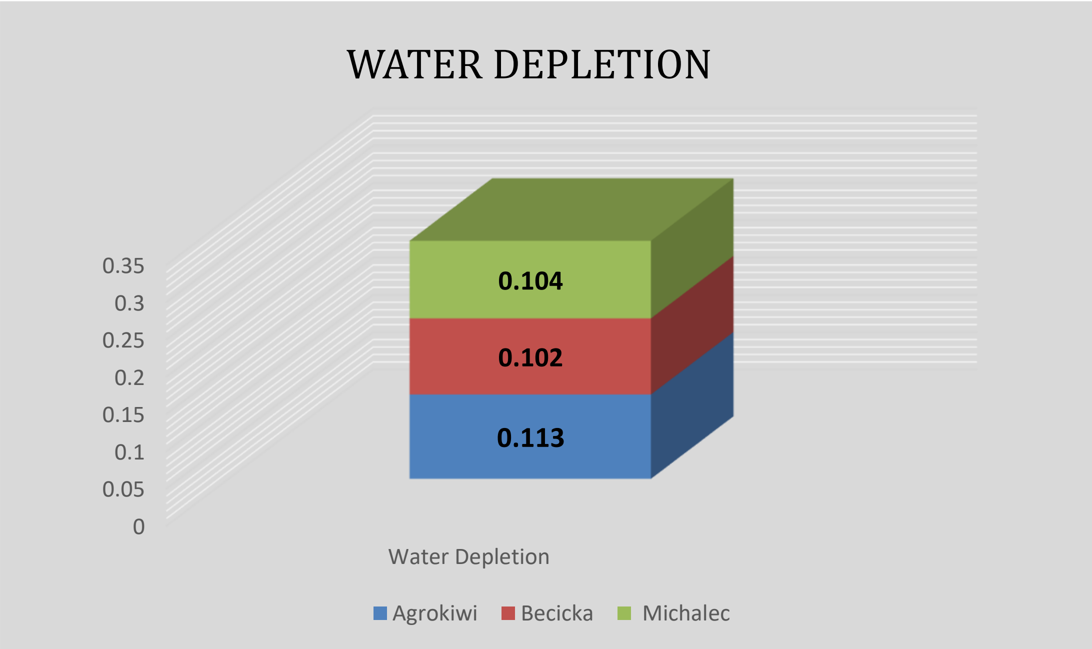

Figure 4.4: Graphical representation of impact category of water depletion

Contribution Analysis
Contribution analysis on Climate change

The results presented in Figure 5 show that the largest contributions to environmental impact in the climate change impact category are caused by the application of NPK fertilizer (15-15-15) and ploughing the fields. For Agrokiwi, tillage ploughing operation and NPK fertilizer application (15-15-15) contributed the most to climate change with 0.0506 kg CO2-equivalent and 0.0237 kg CO2-equivalent respectively, while sowing and transport contributed the least with 0.00979 kg CO2-equivalent and 0.0091 kg CO2-equivalent respectively. The trend in the analysis of contributions remained at the same level in Becicka, as shown ploughing (0.0426 kg CO2-eq.) and the application of NPK fertilizer (15-15-15) (0.0237 kg CO2-eq.) contribute the most, while transport (0.00189 kg CO2-eq.) has the lowest value in the contributions of agrotechnical operations. This results also reveal a relationship between inputs, agrotechnical operations in soybean production, and their contribution to climate change.

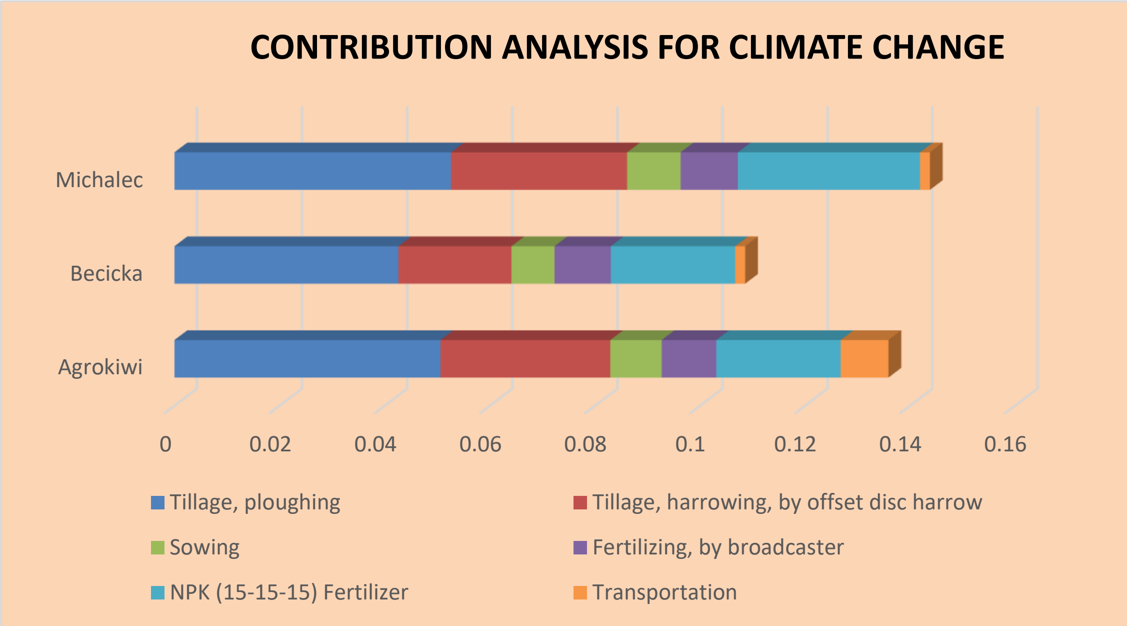

Figure 4.5: Contribution Analysis for Climate change

Normalization

Impact Categories	**Unit**	**Agrokiwi**	**Becicka**	**Michalec**
Climate Change	KgCO2 eq	0.00894	0.00566	0.000305
Water Depletion	m3	x	x	x
Terrestrial Acidification	KgSO2 eq	0.000324	0.000197	0.000112

Table 4.2: Normalization values of the impact categories for the three farms

Normalization of the datasets was considered to capture the most affected impact categories. As can be seen from the normalization model in Figure 6, climate change is the most affected impact category, with Agrokiwi and Michalec farms contributing the highest and lowest respectively (KgCO2 eq 0.00894 and KgCO2 eq 0.00894).

The normalization values of all three farms for water depletion are considered insignificant in relation to the impact of the functional unit on this impact category.

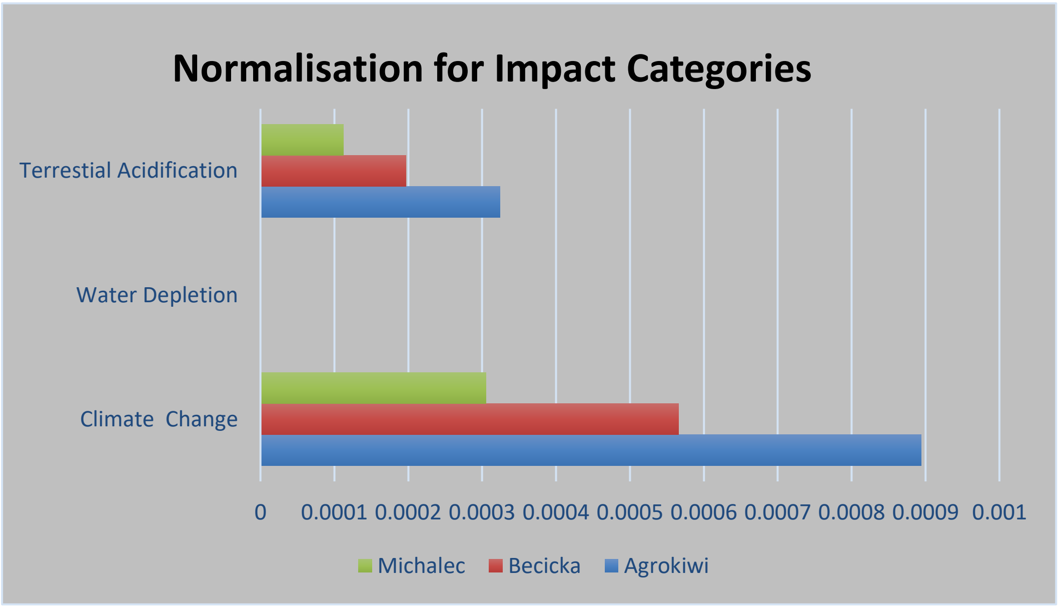

Figure 4.6: Normalization model for the unit of production (FU = 1 kg of soybean)

5. Discussion

Agriculture faces the challenge of ensuring food security for a growing world population without compromising environmental security, as global demand for food is expected to increase in the coming decades. However, achieving net-zero greenhouse gas emissions is possible if awareness is raised, and sustainable and climate-friendly agricultural policies are implemented.

The results, based on the unit of production for the climate change impact category, show that the Agrokiwi farm has a higher environmental impact estimated at (6.17 kg CO2 eq) compared to the Becicka and Michalec farms. As shown by the contribution analysis, the higher impact is due to the overall impact of the agrotechnical practices of tillage and NPK fertilization on the Agrokiwi farm. This result is in line with the findings of (Mukosha et al. 2023.), who in their study on wheat attributed a higher contribution to global warming potential to the use and application of mineral fertilizers in the conventional farming system. This result also confirms (HE et al. 2018), who previously found that the largest GHG emissions released into the atmosphere come mainly from nitrogen fertilizers. (Del Grosso et al., 2009; Smeets et al., 2009; Snyder et al., 2009; Reijnders and Huijbregts, 2008; Miller, 2010) attributed the influence of soybean production on the greenhouse gas balance to farm operations and fertilization in their studies.

As shown in Table 1, the Michalec farm had the lowest environmental impact per unit of production in the climate change impact category (2.1 kg CO2 eq). However, compared to the agrokiwi and Becicka farms, it achieved a higher yield of 3000 kg/ha of soybean grain.

Regarding climate change impact, the Michalec farm system is more environmentally friendly due to the low use of calcium nitrate fertilizer and fertilizer application by broadcasting. However, this was associated with more time spent on crop protection measures and a high amount of nitrogen fertilizer, as shown in Table 1. According to the IPCC (2006), farmers use nitrogen fertilizers to increase their yields. However, these are significant sources of anthropogenic greenhouse gas emissions.

Soybeans are legumes that can fix atmospheric nitrogen through their root nodules. The use of nitrogen-fixing plants in a crop rotation can be a good way to avoid the excessive use of nitrogen in the production system. Disease-resistant varieties can also be used to minimize the use of pesticides, which also reduces the environmental impact of crop production (Brankatschk & Finkbeiner, 2017).

6. Conclusion

LCA is a widely recognized and effective tool for assessing the environmental impact of agricultural systems. Its application in several studies has helped determine the levels of inputs and outputs. More importantly, it assesses the impact of production systems on the environment and natural resources.

The results of this research show that the Agrokiwi farm has a higher environmental impact per unit of production compared to the Becicka and Michalec farms in this study. Thus, the Agrokiwi farm is the least environmentally friendly of the three farms considered in this study and contributes the most to climate change as an environmental impact factor.

The results of this case study show that the environmental performance of soybean production could be significantly improved by switching from synthetic fertilizers to more environmentally friendly organic farming, introducing crop rotations, and using disease-resistant seed varieties as a means of introducing sustainable farming practices/systems.

Fertilizer use has a significant impact on yield and environmental impact. A reduction in the environmental impact of soybean cultivation can be achieved by reducing fertilizer dosage, but at the cost of lower yield.The excessive use of nitrogen fertilizers has an impact on increased environmental pollution.Finally, priority should be given to farms that promote environmental sustainability.

7. References

Alan Buis, 2022. Steamy Relationships: How Atmospheric Water Vapor Amplifies Earth's Greenhouse Effect https://climate.nasa.gov/explore/ask-nasa-climate/3143/steamy-relationships-how-atmospheric-water-vapor-amplifies-earths-greenhouse-effect/

Amit Ray, Archana Rai, S. Ravichandran. Impact of Agriculture Production on Climate: Contributor and Victim. International Journal of Green Chemistry. 2023; 9(1): 33–39p.

Atandi, J. G., Haukeland, S., Kariuki, G. M., Coyne, D. L., Karanja, E. N., Musyoka, M. W., ... Adamtey, N. (2017). Organic farming provides improved management of plant parasiticnematodes in maize and bean cropping systems. Agriculture, Ecosystems and Environment, 247(June), 265–272. https://doi.org/10.1016/j.agee.2017.07.002.

Boone, L., Roldán-Ruiz, I., Van linden, V., Muylle, H., & Dewulf, J. (2019). Environmental sustainability of conventional and organic farming: Accounting for ecosystem services in life cycle assessment. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2019.133841.

Calvet, S., Hunt, J., Misselbrook, T. H. (2017). Low frequency aeration of pig slurry affects slurry characteristics and emissions of greenhouse gases and ammonia. Biosystems Engineering, 159, 121- 132. doi.10.1016/j.biosystemseng.2017.04.011.

Chang, J., Peng, S., Ciais, P., Saunois, M., Dangal, S.R., Herrero, M., Havlík, P., Tian, H., Bousquet, P. (2019). Revisiting enteric methane emissions from domestic ruminants and their δ13CCH4 source signature. Nature Communications, 10(1), 1-14. doi.10.1038/s41467-019-11066-3.

Chianu, N., and Mairura, F. (2019). Soybean Situation and Outlook Analysis: The Case of Tanzania. Available online at: https://www.academia.edu/21091023

Chiriacò, M. V., Grossi, G., Castaldi, S., & Valentini, R. (2017). The contribution to climate change of the organic versus conventional wheat farming: A case study on the carbon footprint of wholemeal bread production in Italy. Journal of Cleaner Production, 153, 309–319. https://doi.org/10.1016/j.jclepro.2017.03.111.

Coskun D, Britto DT, Shi W, Kronzucker HJ (2017) Nitrogen transformations in modern agriculture and the role of biological nitrification inhibition. Nat Plants 3(6):1–10

Courtney Lindwall | National Resources Defense Council 2022. How NRDC leadership helped pass the Kigali Amendment and turn the tide on a common class of super-polluting refrigerant chemicals. https://www.nrdc.org/stories/united-states-finally-joins-global-climate-treaty-phases-down-hfcs

Courtney Lindwall | National Resources Defense Council 2022, From fertilizer runoff to methane emissions, large-scale industrial agriculture pollution takes a toll on the environment. https://www.nrdc.org/stories/industrial-agricultural-pollution-101

Del Grosso, J., Ojima, D. S., Parton, W. J., Stehfest, E., Heistemann, M., DeAngelo, B., & Rose, S. (2009). Global scale DAYCENT model analysis of greenhouse gas emissions and mitigation strategies for cropped soils. Global Planetary Change, 67, 44-50.

Dennehy C, Lawlor PG, Jiang Y, Gardiner GE, Xie S, Nghiem LD, Zhan X (2017) Greenhouse gas emissions from different pig manure management techniques: a critical analysis. Front Environ Sci Eng 11(3):11

Dhar, A. R., Uddin, M. T., & Roy, M. K. (2020). Assessment of organic shrimp farming sustainability from economic and environmental viewpoints in Bangladesh. Environmental Research, 180, 108879. https://doi.org/10.1016/j.envres.2019.108879.

Eggleston, H.S. (Ed.) 2006 IPCC Guidelines for National Greenhouse Gas Inventories; Institute for Global Environmental Strategies: Hayama, Japan, 2006; ISBN 978-4-88788-032-0.

Eloka-Eboka AC, Bwapwa JK, Maroa S (2019) Biomass for CO2 sequestration encyclopedia of renewable and sustainable materials; Elsevier Inc. All rights reserved. https://doi.org/10.1016/B978-0-12-813196-1.10470-5

Fleskens, L., Nainggolan, D., Termansen, M., Hubacek, K., Jansen, J., & Reed, M. (2019). Environmental assessment of farm-level management practices for improved productivity, soil quality and water quality: A case study of rainfed agriculture in the mid-hills of Nepal. Science of the Total Environment. https://doi.org/10.1016/j.scitotenv.2019.06.141.

Franzluebbers, A. J., Stuedemann, J. A., Schomberg, H. H., Wilkinson, S. R., & Zuberer, D. A. (2017). Soil carbon, nitrogen, and soil biochemical properties in response to long-term conservation tillage and cropping systems in the Southern Piedmont USA. Soil and Tillage Research, 165, 55–64. https://doi.org/10.1016/j.still.2016.08.002.

Gouel, C. and Gautier, L. 2021. Organic Agriculture and the Greenhouse Gas Emissions Intensity of Agricultural Production. Environmental and Resource Economics. 78(2), 249-276. https://doi.org/10.1007/s10640-020-00514-w.

Hamidou, F., Ntoupka, M., & Lungu, O. I. (2020). Sustainability of vegetable production systems in Cameroon: Analysis of economic, social and environmental indicators. Heliyon, 6(11), e05501. https://doi.org/10.1016/j.heliyon.2020.e05501.

Hayhoe, K. et al. (2018). Climate models, scenarios, and projections. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II (J. M. Walsh, D. J. Wuebbles, K. Hayhoe, J. Kossin, K. E. Kunkel, G. L. Stephens, P. R. Backlund, C. A. Weaver, D. W. Pierce, T. R. Anderson, J. G. Dobson, R. J. M. DeConto, and D. Mic

Hayhoe, K. et al. (2018). Climate models, scenarios, and projections. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II (J. M. Walsh, D.

J. Wuebbles, K. Hayhoe, J. Kossin, K. E. Kunkel, G. L. Stephens, P. R. Backlund, C. A. Weaver, D. W. Pierce, T. R. Anderson, J. G. Dobson, R. J. M. DeConto, and D. Mic
Ibrahim, M., Ismail, N., Mohd, F., Nordin, M., & Yaakob, Z. (2021). Climate change awareness and public perception towards sustainable agriculture among Malaysian stakeholders. Land Use Policy, 105, 105428. https://doi.org/10.1016/j.landusepol.2021.105428.

International Panel on Climate Change (IPCC). 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

ISO 14044; Environmental Management—Life Cycle Assessment—Requirements and Guidelines. ISO: Geneva, Switzerland, 2006.

ISO 14040; Environmental Management—Life Cycle Assessment—Principles and Framework. ISO: Geneva, Switzerland, 2006.

Joshi, M., Setiadi, Y., & Vorst, J. G. A. J. (2021). The effect of climate change on soil fertility, crop yield, and human health in Indonesia: A review. Heliyon, 7(9), e08039. https://doi.org/10.1016/j.heliyon.2021.e08039.

Khaledian, Y., Sharifinia, M., Mardani, R., Zavadskas, E. K., Streimikiene, D., & Cavallaro, F. (2022). A comprehensive review of sustainable agriculture and its challenges using bibliometric analysis and fuzzy DEMATEL method. Science of the Total Environment, 810, 152153. https://doi.org/10.1016/j.scitotenv.2022.152153
.
Kumar, P., Panwar, N. R., & Ramanathan, A. L. (2021). Sustainable agriculture intensification strategies under a changing climate scenario: A review. Journal of Cleaner Production, 315, 128341. https://doi.org/10.1016/j.jclepro.2021.128341.

Lehman, R. M., and Cambardella, C. A. (2015). Soil science and sustainable agriculture: Contributions of J. LEHMANN, C. A. CAMBARDELLA. Soil Science Society of America Journal, 79(3), 681–692. https://doi.org/10.2136/sssaj2015.05.0198nafsc.

Li, Y., Yan, J., Su, L., et al. (2019). Agri-environmental indicators for the sustainable intensification of agricultural activities in Eastern China. Science of the Total Environment, 666, 759-769.

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., ... & Smith, P. (2019). Food security. In IPCC, 2019: Climate Change and Land:

an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V.

Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. In press.

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., ... & Smith, P. (2019). Food security. In IPCC, 2019: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V.

Miller, S. A. (2010). Minimizing land use and nitrogen intensity of bioenergy. Environmental Science & Technology, 44, 3932-3939.

Monteiro, C. M. D., Ferreira, F. J. A., & Pacheco, F. A. L. (2019). Economic analysis of environmental management practices for the sugarcane production system. Journal of Cleaner Production, 229, 972–980. https://doi.org/10.1016/j.jclepro.2019.05.166.

Mousavi-Avval, S. H., Rafiee, S., Jafari, A., & Mohammadi, A. (2011). Optimization of energy consumption for soybean production using Data Envelopment Analysis (DEA) approach. Applied Energy, 88(11), 3765–3772. https://doi.org/10.1016/j.apenergy.2011.04.014.

Naveed, K., Biala, A. H., Akhtar, M. N., Niazi, N. K., Khan, M. I., Ali, L., & Shahid, M. (2019). Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: A critical review. Environmental Science and Pollution Research, 26(15), 15012–15027. https://doi.org/10.1007/s11356-019-04916-5.

Orrego, C. E., & Ruiz, C. (2022). Bibliometric analysis of circular economy in agriculture: An overview and future directions. Resources, Conservation and Recycling, 178, 105998. https://doi.org/10.1016/j.resconrec.2022.105998.

Perdrial, J. N., Gile, K., Giardino, J., Prater, J., & Kinner, D. (2018). Soil carbon and nitrogen stocks in soil orders under different land use systems in a semi-arid region of New Mexico. Geoderma Regional, 12, 1–9. https://doi.org/10.1016/j.geodrs.2017.10.002.

Prestele, R., Smith, P., Bai, Z., & Bun, R. (2019). Model comparisons of carbon flow and stocks in land-use areas under human influence–a systematic review. Earth System Dynamics, 10(3), 677–709. https://doi.org/10.5194/esd-10-677-2019.

Qu, Y., Zhao, H., Gao, W., & Chen, L. (2017). Optimization and evaluation of a novel combined system for swine manure treatment. Journal of Cleaner Production, 165, 445–453. https://doi.org/10.1016/j.jclepro.2017.07.035.

Raza, M. A., Shah, A. N., Razzaq, A., Zou, X., Mahmood, T., Wei, X., & Chen, Y. (2021). Soil health improvement and sustainable productivity through integrated nutrient management and conservation agriculture. Geoderma, 382, 114722. https://doi.org/10.1016/j.geoderma.2020.114722.

Reijnders, L., & Huijbregts, M. A. J. (2008). Biogenic greenhouse gas emissions linked to the life cycles of biodiesel derived from European rapeseed and Brazilian soybeans. Journal of Cleaner Production, 16, 1943-1948.

Shi, H., Shangguan, Z., Ma, J., & Zhu, Y. (2016). Evolution of soil conservation policies and practices in China. Journal of Soil and Water Conservation, 71(1), 24A-29A. https://doi.org/10.2489/jswc.71.1.24A.

Smeets, E. M. W., Bouwmanw, L. F., Stehfest, E., van Vuuren, D. P., Posthuma, A. (2009). Contribution of N2O to the greenhouse gas balance of first-generation biofuels. Global Change Biology, 15, 1-23.

Snyder, C. S., Bruulsema, T. W., Jensen, T. L., & Fixen, P. E. (2009). Review of greenhouse gas emissions from crop production systems and fertilizer management effects. Agriculture, Ecosystems & Environment, 133(3-4), 247–266. https://doi.org/10.1016/j.agee.2009.04.021.

Tao, Y., Dong, S., Lei, C., Zhang, X., & Wang, D. (2021). Spatio-temporal variation characteristics and influencing factors of drought in Jiangsu Province from 1961 to 2020. Theoretical and Applied Climatology, 1-16. https://doi.org/10.1007/s00704-021-03930-0.

Umanath, M., Das, M., Gopinath, K. A., & Palanisami, K. (2022). Land use change detection and future scenarios assessment in a tropical region using remote sensing and CA-Markov model. Science of the Total Environment, 804, 150027. https://doi.org/10.1016/j.scitotenv.2021.150027.

Vadrevu, K. P., Lasko, K., & Giglio, L. (2022). Climate and land-use drivers of global fire activity from 2002 to 2019. Earth's Future, 10(1), e2021EF002493. https://doi.org/10.1029/2021EF002493.

van der Heijden, M. G. A., Bardgett, R. D., & van Straalen, N. M. (2008). The unseen majority: Soil microbes as drivers of plant diversity and productivity in terrestrial ecosystems. Ecology Letters, 11(3), 296–310. https://doi.org/10.1111/j.1461-0248.2007.01139.x.

Van Paassen, M.; Braconi, N.; Kuling, L.; Durlinger, B.; Gual, P. Agri-Footprint 5.0; Blonk Consultants: Gouda, The Netherlands, 2009; p. 134.

Wang, J., Yang, Z., Liu, X., Wang, L., & Ni, Z. (2022). Economic and environmental benefits of water conservation technologies in arid regions: A case study of the Loess Plateau, China. Journal of Cleaner Production, 332, 130031. https://doi.org/10.1016/j.jclepro.2021.130031.

Yang, W., Xu, C., Zhang, X., Zhang, L., & Liu, J. (2022). The impact of rural development and cropland management on soil erosion in China: A geographically weighted regression analysis. Science of the Total Environment, 805, 150287. https://doi.org/10.1016/j.scitotenv.2021.150287.

Zhang, J., Li, S., Li, J., et al. (2022). Dynamic carbon budget and carbon footprint of crop straw incorporation in agricultural soils in China. Journal of Cleaner Production, 341, 130767.

Zhang, J., Zhang, R., Gao, Y., Dong, W., Dong, R., & Guo, Y. (2022). Evaluating the impact of land use/cover changes on water resources and soil erosion in the Laohahe basin, China. Science of the Total Environment, 804, 150151. https://doi.org/10.1016/j.scitotenv.2021.150151.

Zhang, Q., Hong, W., Chen, Q., Jin, C., Cui, J., & Geng, L. (2022). Impact of climate change on the water resources and agricultural productivity of the Yanhe River Basin, China. Science of the Total Environment, 805, 150237. https://doi.org/10.1016/j.scitotenv.2021.150237.

Zhang, X., Chen, F., Jiang, Y., Ma, Y., & Wang, J. (2022). Changes in soil organic carbon and its fractions under different land use types in a typical karst region, southwest China. Catena, 212, 105646. https://doi.org/10.1016/j.catena.2022.105646.

Zhou, L., Wang, J., Zhao, Y., Zhou, H., & Wu, Y. (2022). Characteristics of soil carbon and nitrogen, and their influencing factors under different management practices in the karst region of Southwest China. Journal of Soils and Sediments, 22(3), 1447–1459. https://doi.org/10.1007/s11368-021-03047-3.

List of Figures

List of Tables