PROJECT DELIVERABLES "GREENHOUSE GASES EMISSIONS OF GREEK COTTON FIBER "

ARPIL 2024

αειφορική

PREAMBLE

The present document consists the final deliverable according to the contractual agreement between BASF HELLAS S.A. and AEIFORIKI S.A. (date of agreement: November 16th 2023). The services that were provided by AEIFORIKI S.A. were the following:

- Calculation of the Carbon Footprint of Cotton Crop in five (5) farms and ginning in Northern Greece.

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1. Introduction

The life cycle assessment (LCA) of cotton fiber is a comprehensive evaluation of the environmental impacts associated within the life cycle of a cotton fiber. The LCA considers a range of environmental impacts, including resource depletion, greenhouse gas (GHG) emissions, water use, and toxic releases. For the purpose of this study the environmental impact of Climate Change is considered. The GHG emissions are calculated and are referred as Carbon Footprint.

The LCA typically starts with the extraction of raw materials and practically the cultivation of cotton, where inputs such as fertilizers, pesticides, and water are used for the growth of crop. The cotton is then harvested and processed successively into fiber through ginning process.

The environmental burden of the fiber is referred to Climate Change and can vary since it depends on a range of factors, such as the geographic location of production, the type of machinery used, and the specific manufacturing processes employed.

Overall, the LCA of cotton fiber highlights the importance of considering the life cycle of a fiber when assessing its environmental impact, and provides insights into the areas where improvements can be made to reduce the carbon footprint. These findings can be used to facilitate decision-making and promote sustainable practices.

Lately, the cotton production in Greece has been accused for the overexploitation of freshwater since its needs for irrigation are significant. A LCA could estimate if these statements are valid and highlight the hotspots of the cotton cultivation according to environmental performance. Lastly, the carbon footprint could be used as a marketing tool as well.

2. Goal and Scope

2.1 Goal of the Study

The purpose of this project is to quantify the greenhouse gas (GHG) emissions for cradle to post-gin fiber production in Greek CSF program.

A carbon footprint is the result of an analysis which measures the GHG emissions associated with an organization, product, or process. The shorthand term “carbon footprint” originates from the fact that carbon dioxide (CO_2), released primarily from fossil fuel burning (oil, diesel, petrol, coal, natural gas, etc.) makes up the bulk of most GHG and is the main contributor to global climate change. Carbon footprint studies also include the impact of other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), which have higher global warming potentials (GWP) than CO_2.

This study includes the impacts of GHGs beyond CO_2, as such GHGs are expressed as carbon dioxide equivalents (CO_2e) units - which normalizes the impact of non-CO2 GHGs to CO_2 levels based on global warming potential.

Understanding the hotspots of GHG emissions that arise from the agricultural and ginning phase of fiber production is a highly relevant indicator so that intervene via actions of climate change mitigation and adaptation.

The goals of this study were to:

1. Calculate the GHG emissions for Certified Sustainable Fibermax cotton production (farm process).
2. Comparison of GHG emissions of farm processes.
3. Calculate the GHG emissions for Certified Sustainable Fibermax fiber production (ginning process).

2.2 Scope of the Study

The product under study in this GHG emissions quantification project is the final post gin fiber. The ginning process is taken place in a ginning plant located in Thrace region and the farm process accounts for the five farm managers of the BlockChain project. Farmers managers involved in the LCA assesment of the pilot project are kept anonimous.

2.3 System Description & Boundaries

The boundaries for this project encompassed two product systems consisting of several processes such as synthetic inputs production (pesticides & NPK fertilizers), pest control, transportation, ginning (Figure 1 & 2). Cotton cultivation comprises seven main tasks: field preparation, sowing, fertilization, crop protection, irrigation, and harvesting. Components excluded from this GHG quantification were human labour, construction of capital equipment, maintenance and operation of supporting agricultural machinery.

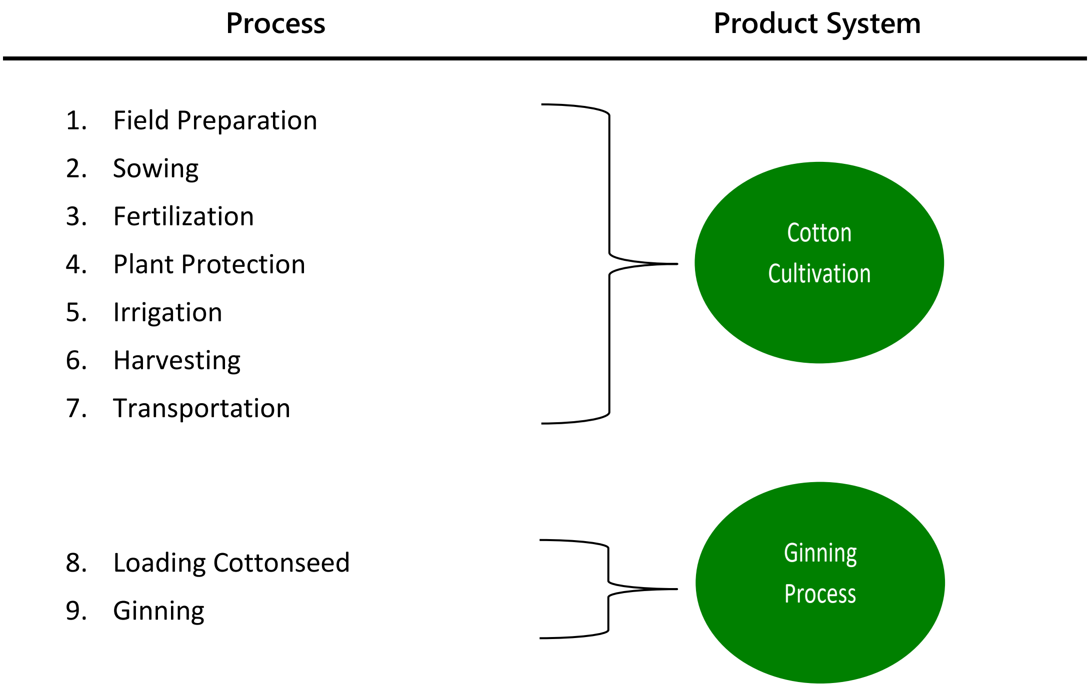

Figure 1: Life Cycle Stages of System

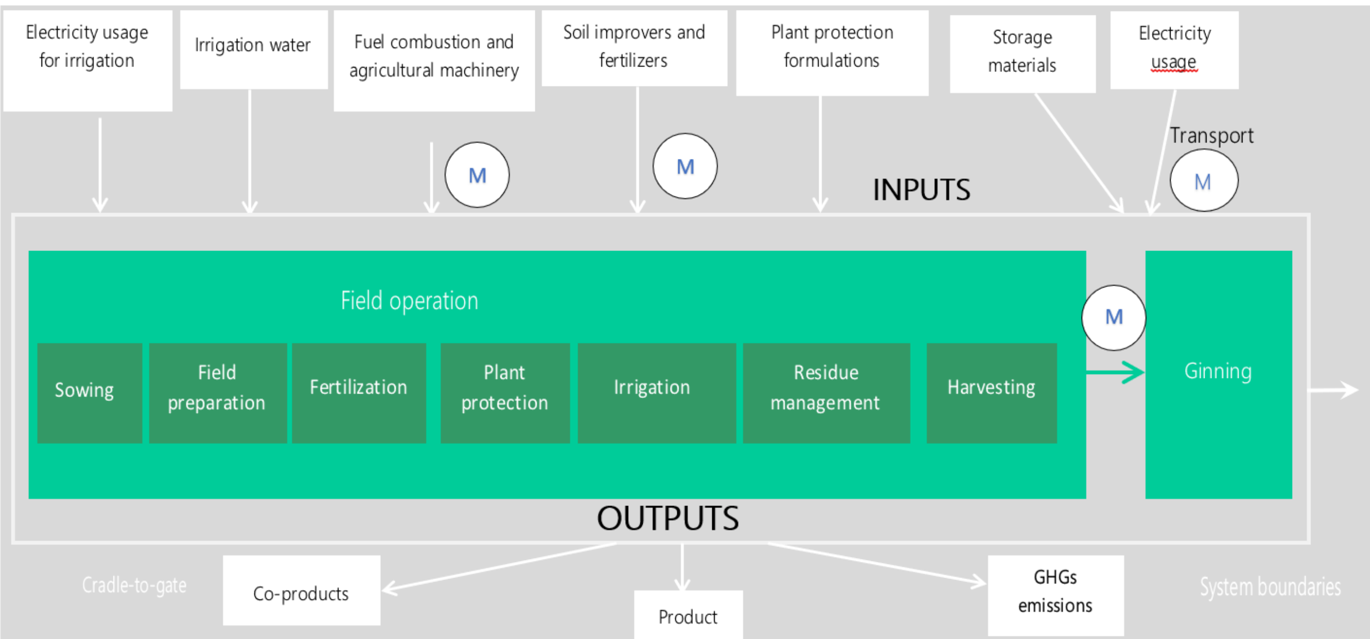

Figure 2: System boundaries of study

2.4 Functional Unit

The cradle to post-gin GHG assessment covers raw material production from field up to and including ginning. Use of a functional unit(s) allows for quantification of the GHG emissions relating to cotton cultivation, transportation to gin and ginning. The GHG emissions in this project have been calculated using the functional unit:

- Kilograms cotton fiber produced (kg fiber)

The comparative analysis of GHG emissions for CSF cotton production is undertaken by the functional unit kg cottonseed harvested.

2.5 Data Collection

All primary data used in this project were collected by personnel of Aeiforiki S.A. The data for this project are consist of the basic field logs of CSF program located in https://www.aeiforiki-afis.gr/:

Additional data are gathered for quantifying the fuel consumption, electricity consumption, operating time of agricultural machinery and service of the basic machinery elements.

As for the ginning, a special questionnaire is developed for gathering ginning data from the Ginning plant.The data are:

- Total Harvested Area,
- Total Cottonseed harvested,
- Total fiber obtained from the gin,
- Electricity & fuel consumption,
- Quantities of packaging and handling materials,
- Co -products or waste materials such as gin motes and trash.
- Transportation

Secondary data accounts for soil texture, soil organic matter, soil moisture, soil drainage and are researched in Soil Map of Greece (http://appliedsoilab.web.auth.gr/images/SOIL%20MAP%20OF%20GREECE%20e-SOILBOOK.pdf).

Special tables are developed for data feeding in the software. These tables are called Life Cycle Inventories and are formatting for each process (Table 1).

Life Cycle Inventory «X»

Input	Value	Unit

Energy Inputs		
Electricity		kWh
Fuel Consumption – Diesel		kg
Fuel Consumption – Petrol		kg
Mass Inputs		
Irrigation Water Applied		m^3
Plant Protection Product I		kg
Plant Protection Product II		kg
Plant Protection Product III		kg
Units of N applied		kg
Units of P_2O_5 applied		kg
Units of K_2O applied		kg
Units of SO_3 applied		kg
Manure		kg
Inputs		
Describe		
Outputs	**Value**	**Unit**
Product		
Cottonseed		kg
Co or by -products		
Cotton Residues		kg

Table 1: Life Cycle Inventory for cotton crop.

2.6 Time & Geographical Coverage

Primary data were collected by the personel of AEIFORIKI S.A. Crop inputs for growing season 2022-2023 were collected through farmers field logs and additional questionaires. Ginning data were also collected through interviews and questionaires. Furthermore, secondary data were reviewed in literature. As a result, it is expected that the impacts of these processes could be less accurate. The geographical coverage for this study is the region of Eastern Macedonia and Thrace Greece. Cotton production and ginning took place in Thrace (Komotini area).

A very important step was the cross-checking and the validation of data in order to assess the data quality. After that, the data feeding on the software of LCA took place in February 2024.

2.7 Software and database

The identification of the specific product systems is the very first step to be determined. The product under study is a 100% fiber made from cotton garment. Its use, disposal and waste are not included in the study. The production phases in order of implementation are the following:

- agricultural production,
- ginning of cotton seed.

Each phase includes inputs, outputs and it is considered as an independent sub-system. Each sub-system ends up to a final output product. The latter is transferred to the next step in product system where it is processed and converted into the final product.

The functional unit is: **1 kg of cotton lint – cotton fiber.** The system boundaries are cradle-to-post gin. This means that the carbon accounting system starts from the extraction of raw materials (production of seed cotton) and ends up to the gate of ginning. Table 2 indicates the flows that are in- or excluded in the study.

Table 2. Flows in- or excluded from the system.

Included	Excluded	Reason
Transport of intermediate & finished products	Human labor	Complexity
Cotton growth	Construction of capital equipment	Continuous use for other products
Energy & Material for each process	Transport of packaging materials	Lack of available data
	Maintenance and operation of support equipment	Lack of available data

2.7 Assessment of data quality

Completeness

All relevant process steps were considered and modelled to represent each specific situation, i.e. cultivation in various farms in different locations were modelled separately. The process chain was considered sufficiently complete with regard to the goal and scope of this study.

Reliability

Primary data were collected using a specifically adapted questionnaire for agrarian systems. Cross-checks concerning the plausibility of mass and energy flows were carried out on the data received. Similar checks were made on the software model during the study. The agricultural model itself was part of the Ecoinvent database. Overall, the data quality with regard to the goal and scope of this study was intended to reach a good level.

Consistency

To ensure consistency, all primary data were collected with the same level of detail, while all background data were sourced either from literature or from Ecoinvent databases. Allocation and other methodological choices were made consistently throughout the model.

2.8 Allocation

When a process yields more than one valuable outputs, environmental burden between products and co-products must be shared. Generally, the procedure of allocation is based on terms of economic value or mass. In this study mass was used as a factor for environmental burden distribution. In most cases data were obtained from stakeholders, for instance:

- during ginning the produced lint accounts for the ***39.7%*** of total seed cotton weight,

2.9 Software and Database

The LCA model was created using the SimaPro software system version v.9.5.0.2 for life cycle engineering. The SimaPro software includes many Life Cycle Inventory (LCI) databases, including the renowned ecoinvent v3 database. The ecoinvent database is a compliant data source for studies and assessments based on ISO 14040 and 14044. Also, ecoinvent is widely recognized as the largest and most consistent LCI database on the market.

2.10 Nutrient Modelling

Nitrogen plays a fundamental role for agricultural productivity and is also a major driver for the environmental performance of an agricultural production system. For these reasons it is essential to evaluate all relevant nitrogen flows within, to and from the agricultural system. The agricultural model accounts for the nitrogen cycle in agricultural systems.

Moreover, it has been considered the emissions of fertilizer production and the emissions of fertilizers used have been taken into account. Nitrogen (N_2O), phosphorus (P_2O_5) and potassium (K_2O) emissions were modelled according to the literature (Bentrup et al., 2001; Audsley, 1997). As regards diffuse emissions, according Audsley (1997), it was assumed as 2% of NH_3 volatilization for simple nutrient fertilizer (ammonium nitrate), and 4% for multinutrient fertilizer (NPK). NO_x emissions were assumed as 10% of the N_2O emissions. The N_2O emission factor assumed for all fertilizers is 1.25% of N addition (Bentrup et al., 2001).

3. Life Cycle Impact Assessment

3.1 Selection of Life Cycle Impact Assessment (LCIA)

An impact assessment method is a set of procedures and techniques used to quantify and evaluate the potential impacts of a product, process, or activity on the environment, human health, and social well-being. Impact assessment methods are used in various fields, including environmental management, sustainability science, and life cycle assessment studies. There are many different impact assessment methods available, however the selection of a particular method depends on the goals of the assessment, the availability of data and resources, and the preferences of the stakeholders involved. It is important to use a transparent and scientifically sound approach when selecting and applying an impact assessment method to ensure the results are robust and reliable.

The LCIAM which was chosen in this study is the IPCC 2021 method (successor of the IPCC 2013), which was developed by the Intergovernmental Panel on Climate Change (Masson-Delmotte et al., 2021). It contains the Global Warming Potential (GWP) climate change factors of IPCC within a timeframe of 100 years. GWP is a term used to describe the relative potency of a greenhouse gas, taking account of how long it remains active in the atmosphere. The GWPs currently used are those calculated over 100 years. Carbon dioxide is taken as the gas of reference (GWP= 1). A carbon dioxide equivalent or CO_2 equivalent (CO_2-eq) is a metric measure used to compare the emissions from various greenhouse gases on the basis of their GWP. The current impact assessment method was based on the IPCC report 'AR6 Climate Change 2021 (Arias et al., 2021). This version of impact assessment does include CO_2 uptake and biogenic CO_2 emissions. The results can be calculated cumulatively as GWP100 per category but in this study is aggregated into a single impact assessment result by selecting Damage assessment in SimaPro.

3.2 Results

The following table (Table 3) illustrates the results of the study. The climate impact is expressed in kg CO_2eq per kg of fiber.

Process	Company	Final Product	kg CO_2eq / kg final product	Performance rate	Product quantities (kg) per process	kg CO_2 eq produced	Contribution to final carbon footprint of post gin gate
	1		**1.02**		354.900	361.028,91	
	2		**0.77**		239.350	184.288,84	
Farm	3	Cottonseed	**0.96**		223.940	214.546,45	**91%**
	4		**1.0**		125.210	125.208,19	
	5		**1.4**		204.440	286.092,28	

Ginning	1	Fiber	**1.16**	39.7%	451,434.5	525.351,38	-

Table 3: Results of LCA on system

3.3 Interpretation

Farming process

The carbon footprint of agricultural sector (average of 5 five farm-managers) was measured to be **1.03 kg CO_2eq / kg seed cotton** (Figure 3).

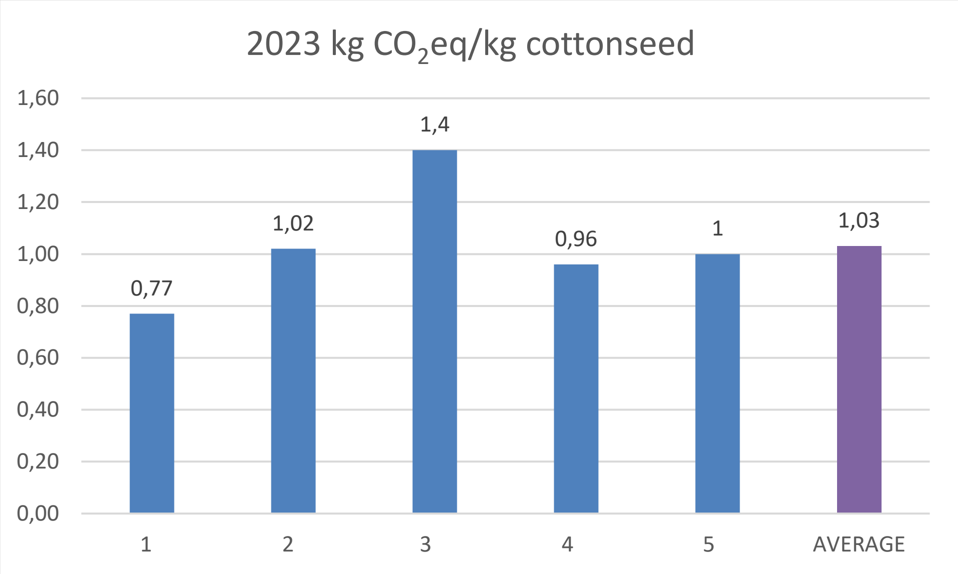

Figure 3: Results of cotton crop for CSF farm-managers

A comparative analysis between the two years is showed on the bellow figure as well (Figure 4). The contribution of each source in GHG emissions for each farm-manager is showed in Figures 5, 6, 7, 8, 9.

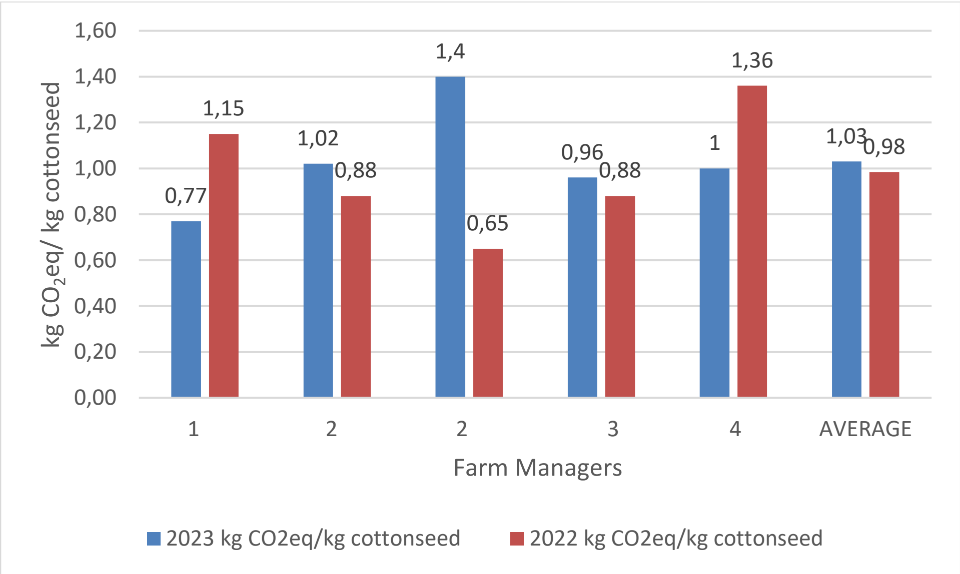

Figure 4: Comparative analysis between the 2022 vs 2023 of carbon assessment.

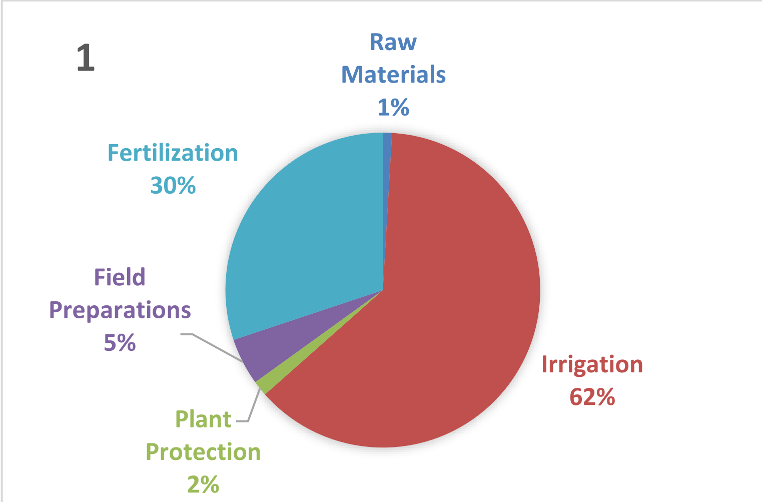

Figure 5: Contribution each source in GHG emissions for Farm Manager 1

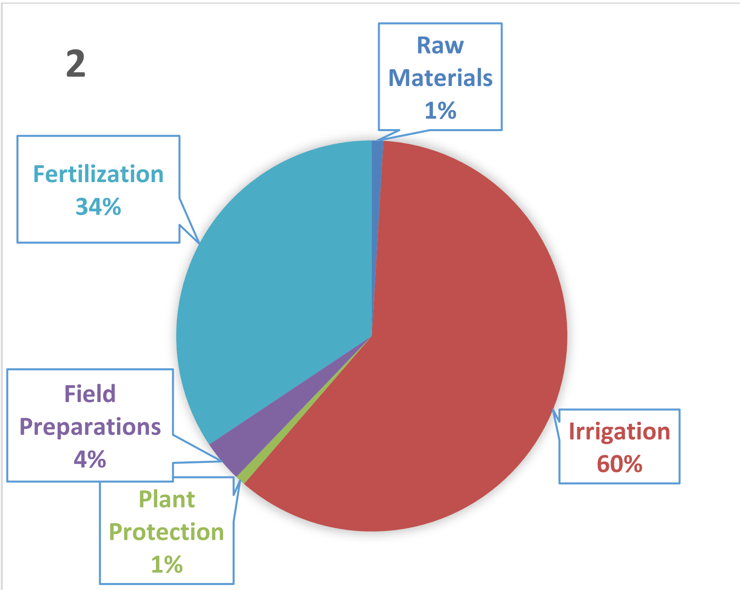

Figure 6: Contribution each source in GHG emissions for Farm Manager 2

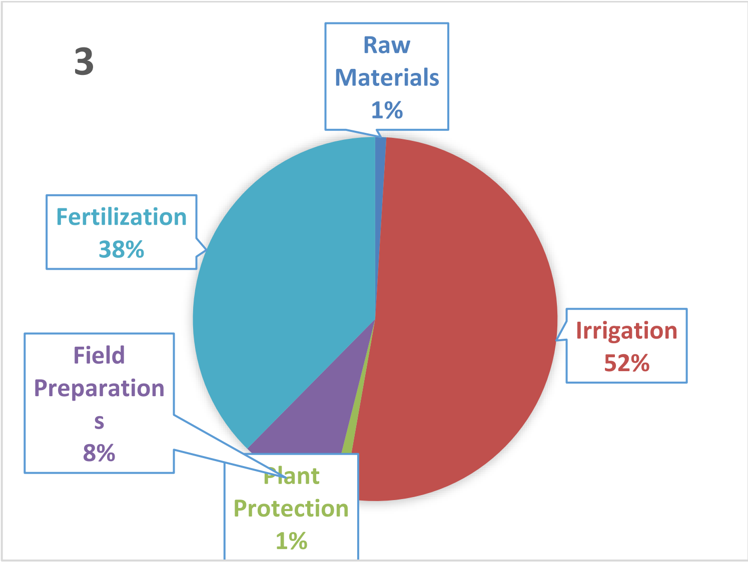

Figure 7: Contribution each source in GHG emissions for Farm Manager 3

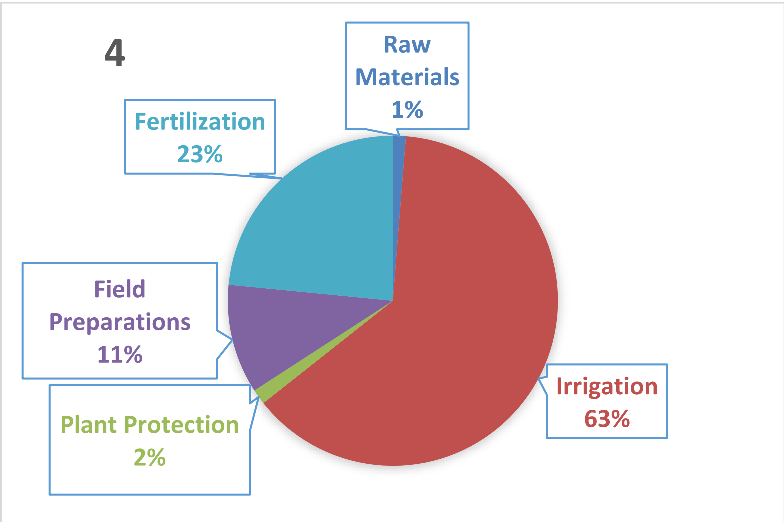

Figure 8: Contribution each source in GHG emissions for Farm Manager 4

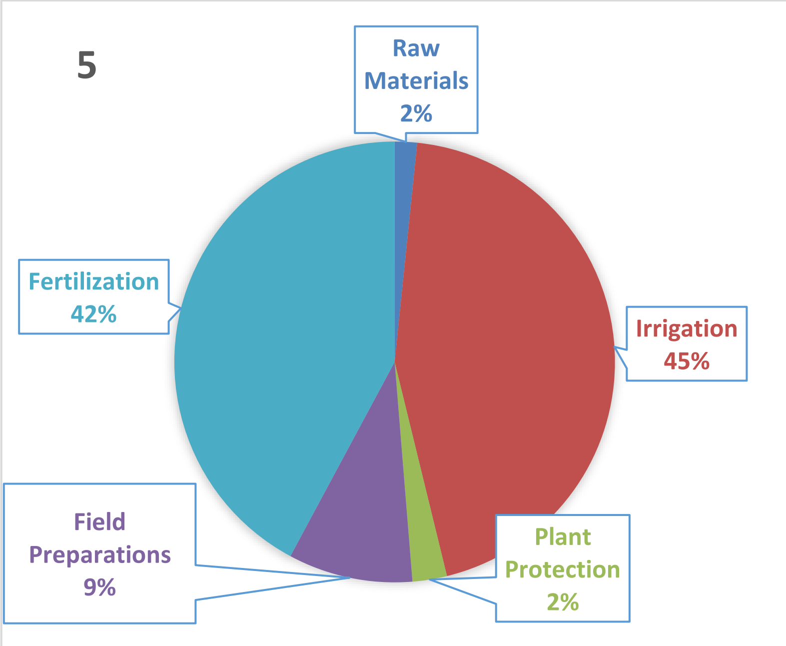

Figure 9: Contribution each source in GHG emissions for Farm Manager 5

Overall, it could be said that the process of **Irrigation** is the major contributor of GHG emissions for each farm-manager. Secondly, the **Fertilization** accounts for 33.5% approximately in average for the crop production. Transportation is included in Field Preparation as inputs of diesel and it is not calculated separately due to the usually small contribution to the whole process of plant production. In process Field Preparation is included the use of agricultural machinery and specifically the hours operating of the tractors and the diesel consumption of all the field operation (tillage harrowing etc.). The process of Raw Materials is the extraction and the supply of seed for sowing and auxiliary materials such as lubricating oils.

Considering the five (5) farms that participate in the blockchain as a uniform agricultural process, it is concluded that farming is responsible for **91%** of total carbon emissions in the system product (ginning and farming).

For the purpose of interpretating the results and why the irrigation is playing the major role of the environmental performance, some important key performance indicators - KPIs (water, fertilizer and fossil fuels use) are displayed in figures 10 & 11.

There are slight differences in the literature concerning the electricity used for ground water extraction e.g., in Spain and Turkey [Soto-Garcia et al. (2013) vs Yavuz et al. (2014)]. The energy consumption variability for groundwater extraction may be attributed to the differences in elevation pressure head, in climate and soil conditions and finally to the water table depth (Soto-Garcia et al., 2013). In this study the average value is 0.8 kWh/m^3 which is in line with the literature.

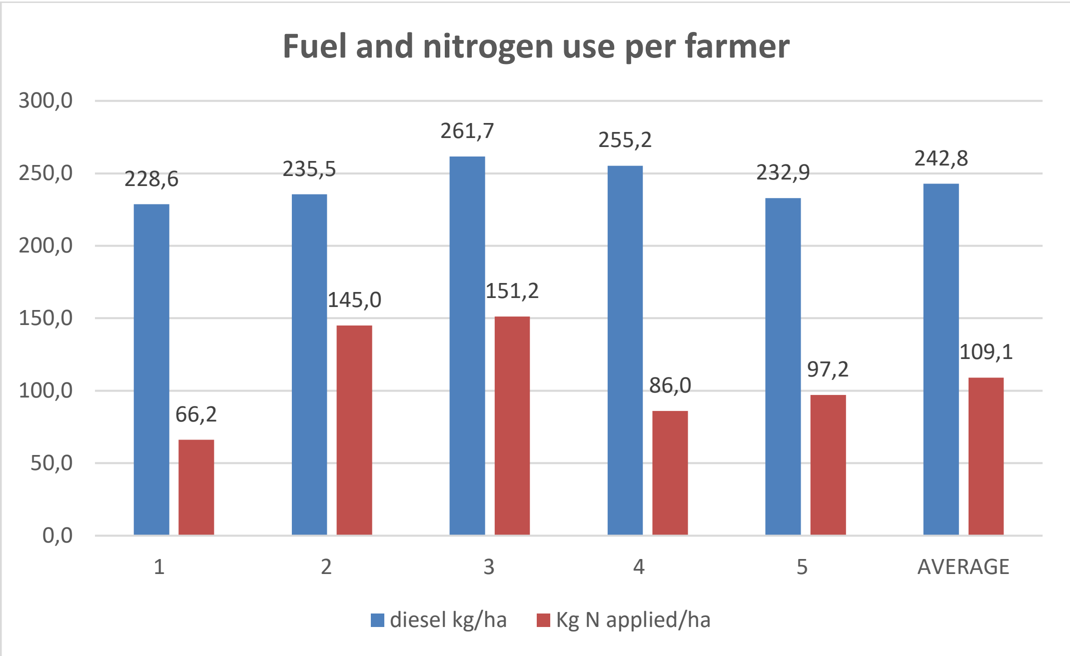

Figure 10: Fuel and nitrogen use per farm manager.

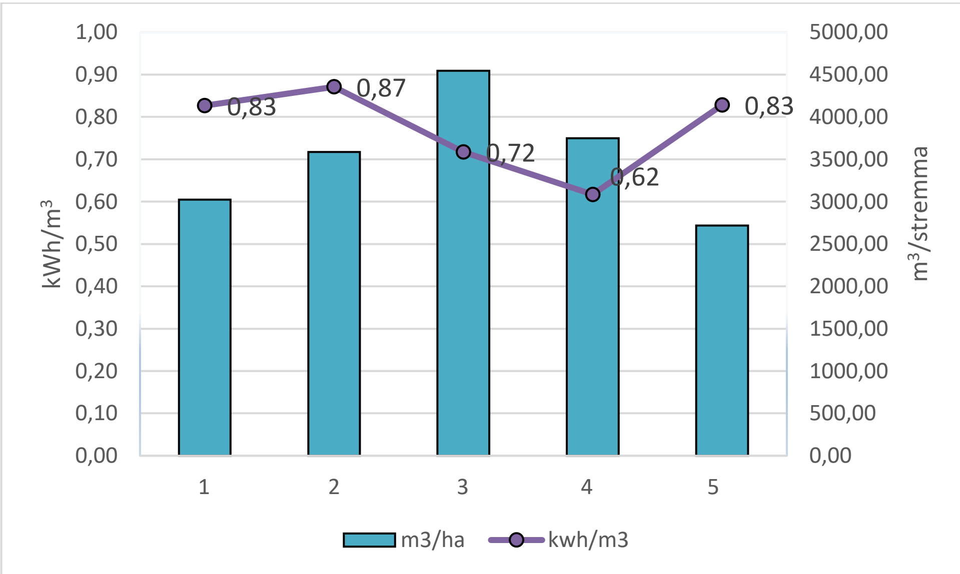

Figure 15: Water quantities and electricity used for irrigation.

Ginning process

The ginning process itself produces **1.16 CO_2eq/kg of cotton lint**.

All steps in the supply chain carry environmental burdens from the previous one. Almost **91%** (90.69%) of the environmental burden in ginning is due to farming (processed data). Electricity and transport of goods are responsible for **4.64** and **4.19%** respectively of GHG emissions during ginning (figure 11). The steam production is referring to fuel consumption (diesel, LPG, combustion of gin waste).

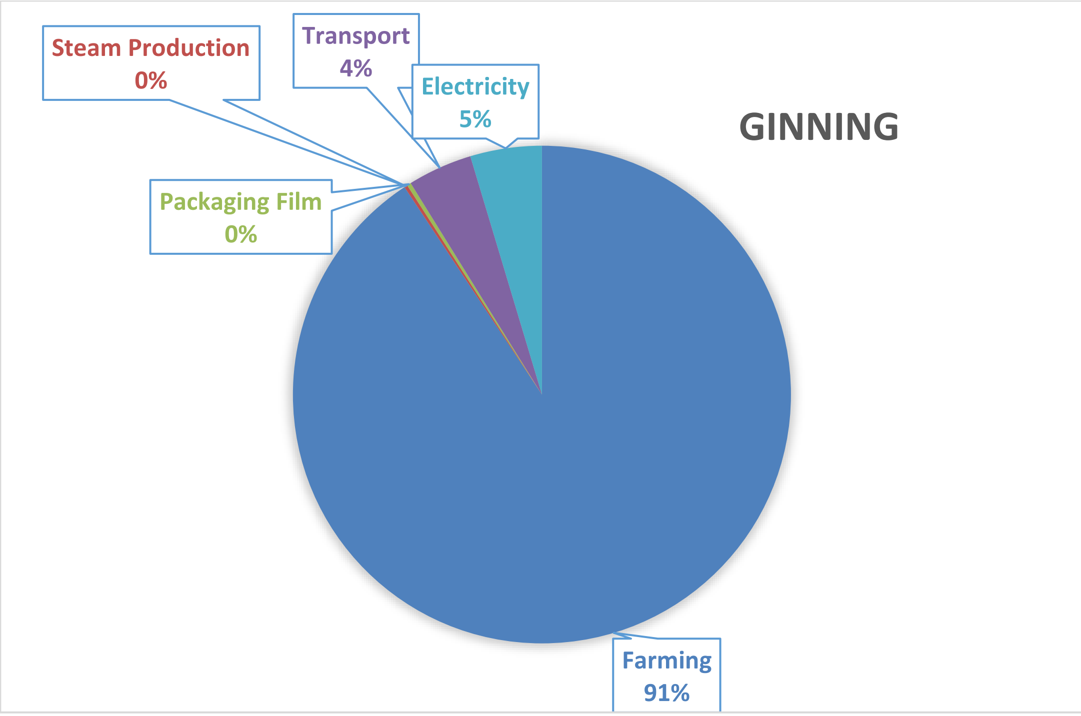

Figure 11: GHG contributing factors during ginning

It is clear that ginning process **has a very robust performance over its carbon emissions**. The fact of circularity of cotton seed which is a co-product and it is used inside in model process as a material of combustion for steam production is a big asset for diminishing the carbon emissions. In other studies, farming and ginning are often considered as one process [Roos et al. (2015), Sandin et al. (2019), Anthesis 2021]. Khabbaz et al. (2010) reported 3.2 kg CO2-eq/kg textile for fibre production.

5. Conclusions

The conclusions that can be drawn from this study are the following:

- This study as the previous year one, indicates that the irrigation and use of fertilizers are the main contributors in carbon footprint (above 85%) during farming. The Cool Farm Tool indicates as main contributors primarily the energy use and the irrigation
- Ginning seems to have a very robust environmental performance regarding the carbon emission.
- The carbon data and results should be used for Economic Tool for carbon market.
- The LCA studies could be used for creating the Environmental Product Declaration, in order to communicate environmental performance to customers.

6. References

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