UNIVERSIDADE FEDERAL DE SÃO CARLOS
DEPARTAMENTO DE ENGENHANHARIA DE PRODUÇÃO DE SOROCABA

OVERALL LEAN & GREEN EFFECTIVENESS BASED ON THE SUSTAINABLE VALUE STREAM MAPPING ADAPTED TO AGRIBUSINESS

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Sorocaba
2024

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Trabalho de conclusão de curso apresentado como requisito parcial para a obtenção do título de Bacharel em Engenharia de Produção pela Universidade Federal de São Carlos.

Orientador: Diogo Aparecido Lopes Silva

Sorocaba
2024

Abstract

Purpose This paper aimed to implement Lean & Green principles in agribusiness, specifically by using Sustainable Value Stream Mapping (Sus-VSM) to evaluate key indicators for the present and future states of an orange farm. The goal was to enhance value while minimizing environmental impacts.

Design/methodology/approach – This study utilizes a mixed-method research approach, incorporating both qualitative and quantitative methods. It adapts Sus-VSM and introduce inventory analysis blueprints for use in the agricultural sector, employing a case study on an orange farm in Sergipe, Brazil. The research aims to offer practical insights when applying Lean & Green principles in agribusiness, introducing also the Overall Lean-Green Effectiveness (OLGE) as a novel decision-making indicator for managers.

Findings – The research highlight the potential of Sus-VSM in agriculture but suggests the need for some process adjustments for successful implementation. The study's indicators reveal that the current state generates 70.55% more impacts (0.47 tCO_2e/ha), and the future state could add 4.08% more aggregated value. The OLGE could be increased by up to 137% from the current to the future state scenario if improved the stocks management of inputs in the field.

Originality – The adaptation of VSM for farm operations along with the inclusion of sustainability indicators represents a novel approach to improving agricultural processes while controlling environmental impacts. A new Lean & Green indicator was proposed, the OLGE, to facilitate interpretation of results and create improvement suggestions.

Keywords Critical – Agricultural production; Waste reduction; Sustainability; Lean thinking.

Paper Type – Research Paper.

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1. Introduction

The share of agribusiness (agriculture, forestry and fishing) in global GDP was 4,3% and in Brazil 6,8% in 2022 (The World Bank, 2023). In the context of small producers, they make up 84% of the Brazil's properties in recent years (IBGE, 2017). Therefore, the use of strategies that can assist in the management of land use and natural resources becomes essential since many of the smaller producers have knowledge gaps in terms of the lack of production management skills (Roop *et al.*, 2022). Lean production, one of the main production strategies to assist in industrial operations management, has its origins in the industrial sector in Japan, but can also be used to agribusiness (Powell *et al* ., 2017). However, research in lean agribusiness is less studied than lean manufacturing and faces some practical challenges yet (Melin and Barth, 2018).

It is evident that the agribusiness sector has some distinct characteristics from the industry; for example, agribusiness is affected by both internal and external factors to the rural property (Caicedo *et al.*, 2020; Melin and Barth, 2020). Additionally, farms deal always with perishable products, requiring special care (Adeyeri and Kanakana, 2015) characterizing an environment highly variable (Marinoudi *et al.*, 2019). Therefore, agrobusiness faces uncertainty (Powell *et al.*, 2017), the production is diffuse and seasonal and has long lead time.

According to Melin and Barth (2018), it is not entirely clear how to implement lean principles and tools for farm operations management specially for small producers. Furthermore, there is a growing demand from the population for more sustainable (green) production systems, and agribusiness cannot be excluded from this trend. The look for sustainable food is relevant, as this is considered today as one of the major areas of consumption footprint (Genta et al., 2022; Giusti et al., 2023) and towards the climate change fight.

Value Stream Mapping (VSM) is the main Lean tool because it provides quantifiable benefits for managers (Marques et al., 2022; Melin and Barth, 2020; Muñoz-Villamizar *et al*., 2019). It involves two stages: mapping the Current State and the Future State of a production system; then, the results are compared using key process indicators and by creating action plans to add more value to production (Ufua *et al*., 2021). However, there is a scarcity of studies on "Lean and Green" or the use of VSM in sustainable agribusiness (Marques *et al*., 2022).

There are many different applications of VSM in literature such as in the industrial processes of food processing (Nandakumar et al., 2020), plastic bag manufacturing

(Deshkar, et al., 2018), textiles (Prasad et al., 2020) and pharmaceutical products (Karam et al., 2018). However, there are few applications in agribusiness (Carrijo, 2021) and even lesser are the number of applications when using VSM under the sustainable production perspective. According to De Oliveira Rezende *et al.*, (2022), the use of VSM can also assist the sustainable/green production by adopting new measures and indicators such as the materials resources, water, chemicals, and energy consumptions or by measuring the amount of waste generated in a production stream. Due to the 'net-zero' movement, where companies must focus on reducing their life cycle greenhouse gases emissions (Sartal *et al.*, 2020), the carbon footprint as a 'green' indicator emerges in recent years (Leme Junior *et al.*, 2018). The idea of Lean & Green accounts for increasing the value in companies' value chain (Kalemkerian *et al.*, 2022).

Marques *et al*. (2022) affirms that the studies of Lean & Green are limited to more industrial applications and de Oliveira Rezende *et al*. (2021; 2022) recently showed a novel application of Lean & Green in the construction and building sector. Therefore, there is a gap of looking for more applications of Lean & Green in different case studies and processes, including the agrobusiness sector too (Paula e Silva *et al.,* 2022).

Regarding applications of Lean & Green in the agribusiness, Barth *et al.* (2017) showed that using VSM is possible to understand the value creation in a farm, while keeping impacts under control by monitoring climate change using a Sustainable VSM (Sus-VSM) approach. Also, Powell *et al*. (2017) applied lean and six sigma in a food processing industry and suggested some environmental improvement opportunities. Six sigma theory and tools can be successfully applied in food manufacturing processes to analyze and improve capabilities while keeping work standardized, but its use in agriculture, for example, have limitations due to climate issues and other natural sources of heterogeneity that can create more uncertainties than manufacturing operations management.

Estrada-Gonzalez *et al.* (2020) reduced the environmental impacts of an egg production using Sus-VSM, where life cycle assessment (LCA) methodology was adopted to the establishment of a set of 'green' indicators in the value flow. Recently, Viles *et al.* (2021) provided a study regarding water management in a agri-food industry, and applied Lean & Green practices to highlight opportunities to reduce water consumption.

Most of these case studies adopted the VSM tool for mapping the main processes and materials entering and leaving the value streams. Also, the Sus-VSM approach is combined with LCA or other environmental management tools to assist a green monitoring. In terms of Lean and Green indicators, eco-efficiency indexes are being used by De Oliveira Rezende *et al.* (2022) for analyzing sustainable construction sites, and by Marques *et al.* (2022) in the production of beverages. However, there is still no papers published about Lean, Green and eco-ecoefficiency indicators for the agribusiness, and this paper aims to fill this gap.

Marques *et al.* (2022) have proposed also a new indicator based on the Overall Equipment Effectiveness (OEE) to correlate product added value with the environmental impacts related to water footprint of beverages. OEE can be used to complete VSM analyzes, as it measures different types of losses and indicates opportunities in the shop-floor area by identifying the percentage of manufacturing time that is truly productive considering availability, quality, and performance as main parameters. However, OEE is a performance measurement that fails in the measurement of environmental issues in Lean & Green studies. It has been used also as the main reference indicator to compare the Current vs. the Future state production scenarios during the Lean studies. Therefore, the VSM and OEE are simple Lean-based tools adopted by recent papers trying to integrate 'Green' aspects also in the production site for monitoring and improvements in the shopfloor. According to Paula e Silva *et al.* (2022) such tools could also enhance more relevant information when applied to other types of production systems, like logistics, office services and agrobusiness.

Based on this, this paper presents an adaptation of the VSM applied to agricultural production based on the application of Lean & Green principles. A case study was developed for a small-sized farm of oranges in Brazil, with the aim of adding more value with minimal environmental impacts to the product.

It is worth noting that the VSM model used in this paper was adapted from Carrijo (2021), and its main differences include the use of more metrics to measure the farm performance including green indicators (e.g., eco-efficiency) and the quantitative analysis of stocks over the value stream. Therefore, as a novelty of this proposal, the adapted VSM can assist more similar farms and other agricultural systems towards a more sustainable production.

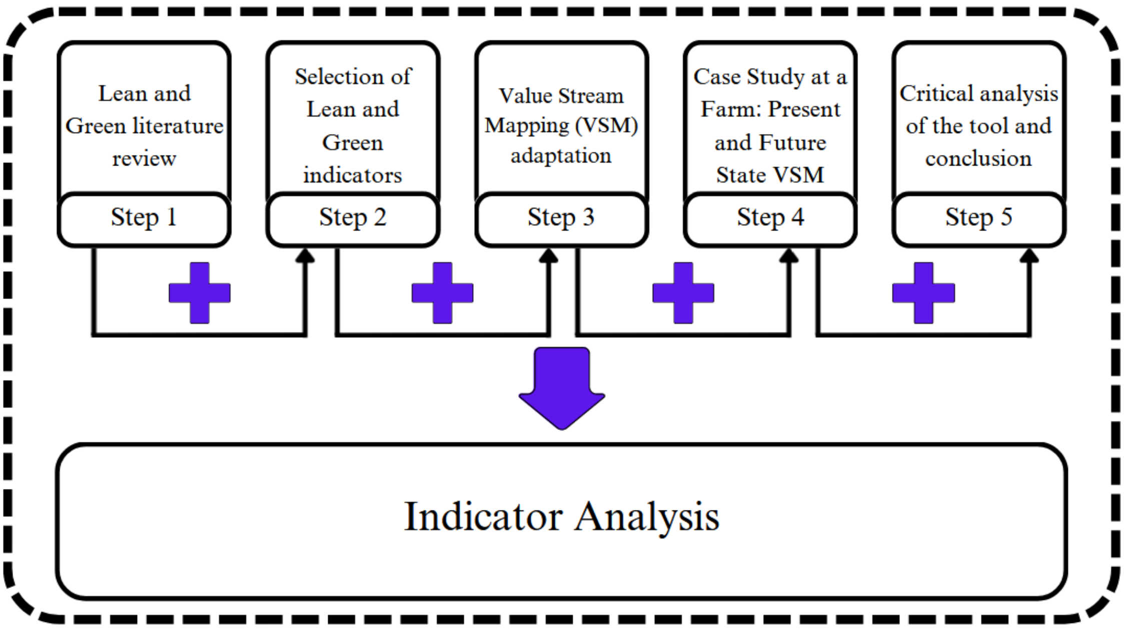
2. Research methodology

The development of this paper involved five steps described on Figure 1, as follows: (i) Lean and Green literature review, (ii) Selection of Lean and Green indicators, (iii) Value Stream Mapping adaptation for sustainable application in agrobusiness, (iv) Case Study at a Farm level and (v) Critical analysis and conclusion.

It is important to emphasize that the first step of the research was conducted using the SCOPUS database, employing the following keywords: "Lean production" OR "Value Stream Mapping" OR "Lean tools" OR "Lean Farming" OR "lean techniques" OR "lean principles" OR "lean and green" AND "Agriculture" OR "Agricultural" OR "Farm" OR "Farming" from the work performed by Freitas et al. (2022). The second step involves the careful choice of performance indicators related to lean efficiency and environmental sustainability to be incorporated into the VSM adaptation.

Regarding the third stage, two distinct phases of VSM adaptation were carried out: the 'Current State' phase and the 'Future State' phase (Figure 2). Fourth step was the application of the adapted tool in a case study conducted on a small orange farm located in the northeastern region of Brazil, in the interior of the State of Sergipe. Finally, the last step was the Lean & Green interpretation of the results followed by the critical analysis of the adapted tool and then the conclusions of the research.

Figure 1: Methodology research steps



Source: Author's own

2.1. The Sus-VSM application: steps 1 to 3

The VSM model was first adapted from Carrijo (2021). However, several adjustments were made, primarily the incorporation of more and new metrics and indicators to measure the farm's performance including various categories of environmental sustainability. One of the main differences from Carrijo's model (2021) is the VSM approach to the environmental sustainability analysis (the Sus-VSM) This is because, according to Muñoz-Villamizar *et al*. (2019), there is a gap in research focused on measuring data for sustainability in Lean & Green studies.

According to Carrijo (2021), the VSM diagram representing the agricultural value stream should be structured into 5 rows from top to bottom, as follows: Information, Inputs, Events, Timelines, and Problems (Current State) or Solutions (Future State). However, the model presented in here differs significantly from this original proposal with the main differences related to the addition of a new column in the VSM diagram for representing suppliers and another one for customers, in a value chain perspective. Also, a complementary flow diagram is adopted to represent the stocks of resources overtime and space during the current and future VSM states. A combination of new metrics and indicators about Lean and Green was also prepared to enhance the diagrams with valuable information to assist decision making processes toward a more sustainable agribusiness.

Figure 2 represents VSM model used in the current research. The columns are numbered from 1 to 4, and the rows in column 2 range from A to F. Starting by column (1), it is a schematic presentation of suppliers: industries supplying raw materials to the farm via road transport and under a certain frequency. Just below that, there is the presentation of the figures used in the model, including electronic message arrows (→), information request icons (→), number of employees ( ), and inventory icons (Δ), among others. Beneath that are the following information about the farm: total planted area and total available area, information about the work pattern (shift and working days per month), and the farm's location.

In the column (2), there are the titles for each data row, from top to bottom: Information (line A), Inputs (line B), Processes and Equipment (Line C), Metrics (Line D), Timelines (Line E), and Problems (Current State) or Solutions (Future State) (Line F) The rows A and B and D to F pertain to each process in the row C.

The Information row contains the data necessary for the processes, such as climate checks, fertilization needs, weed quantity, soil analysis, etc. Just below that, there are the

Inputs row, listing the raw materials required for successful production and their status: in stock or outsourced.

After that, there is the Processes and Equipment section, where general farm processes (Soil Preparation, Seedling Treatment, Planting, Orchard Maintenance, Harvesting, and Weighing), equipment (e.g., tractor, high-pressure washer, trailer), and the number of employees involved are identified.

The metrics section presents Lean and Green indicators that enable the evaluation and comparison between the current and future states.

Continuing, the next section is the Timelines row. At the end of this, there are the production lead time (including stocks) and processing time data in days.

Finally, the last row, in the Current State, pertains to problems found in the production system, while in the Future State, it relates to solutions for the previously identified problems (i.e., flow kaizens).

Column (3) corresponds to the data present in each of the rows. This is the most crucial part of the VSM as it presents the key information about the farm under analysis. It's worth mentioning that there are red spheres, indicating that in certain information, processes, inputs, etc., there is some problem that needs to be resolved. Additionally, it's relevant to note that elements in one row connect with elements in other rows through arrows.

Finally, in the last column (4), there is a schematic presentation of customers, similar to the supplier column: farms supplying oranges to both the industry and the markets through road transportation.

The data for the case study application to test the Sus-VSM tool were primarily obtained digitally from online meeting with the farm manager. But part of the relevant data and information was also gathered in-person, to consolidate the Future State scenario, and for this, technical visits to the farm were conducted for 2022 year.

Regarding the adopted sustainability indicators, carbon footprint, material and water consumption, and land use were selected as the main metrics as these are relevant environmental issues in the agricultural context (de Freitas *et al.*, 2022; Giusti et al. 2023).

The information collected spans from January 2021, the start of the Soil Preparation stage, to January 2023, during the third orange harvest in the area. Therefore, considering the farm and the product in question the studied value stream covers a two-year period.

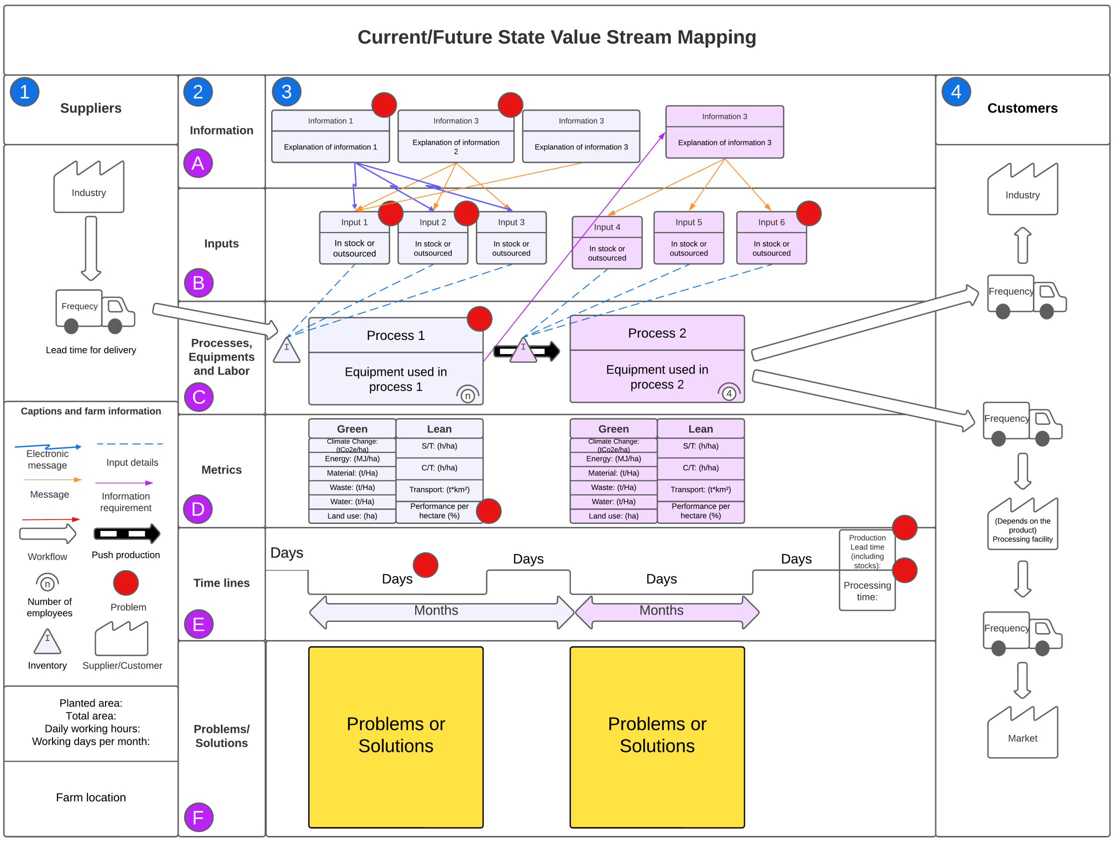
However, it's important to note that this duration can vary drastically for various reasons, including the type of cultivated product, the farm's capacity for investments, productivity of the cultivated area, soil quality, water and nutrient supply for plants, pesticides application needs, and climatic conditions, among others.

The 'Blueprint for Stock Analyses’ was designed for this research to assist in representing the Step 3 in the agricultural sector. Similar to the VSM, the farm's blueprint was divided into two states: Current and Future. These resources enabled the analysis and comparison of the farm's status in terms of its generation and management of stocks in production.

The blueprint diagrams were developed to delve deeper into the analysis of the farm's stocks, which significantly impacts the value aggregation within the workflow. They were separated from the VSM to create a dedicated tool for organization and comprehension of the stock's effects in the value stream. Figure 3 illustrates the blueprint diagram tool.

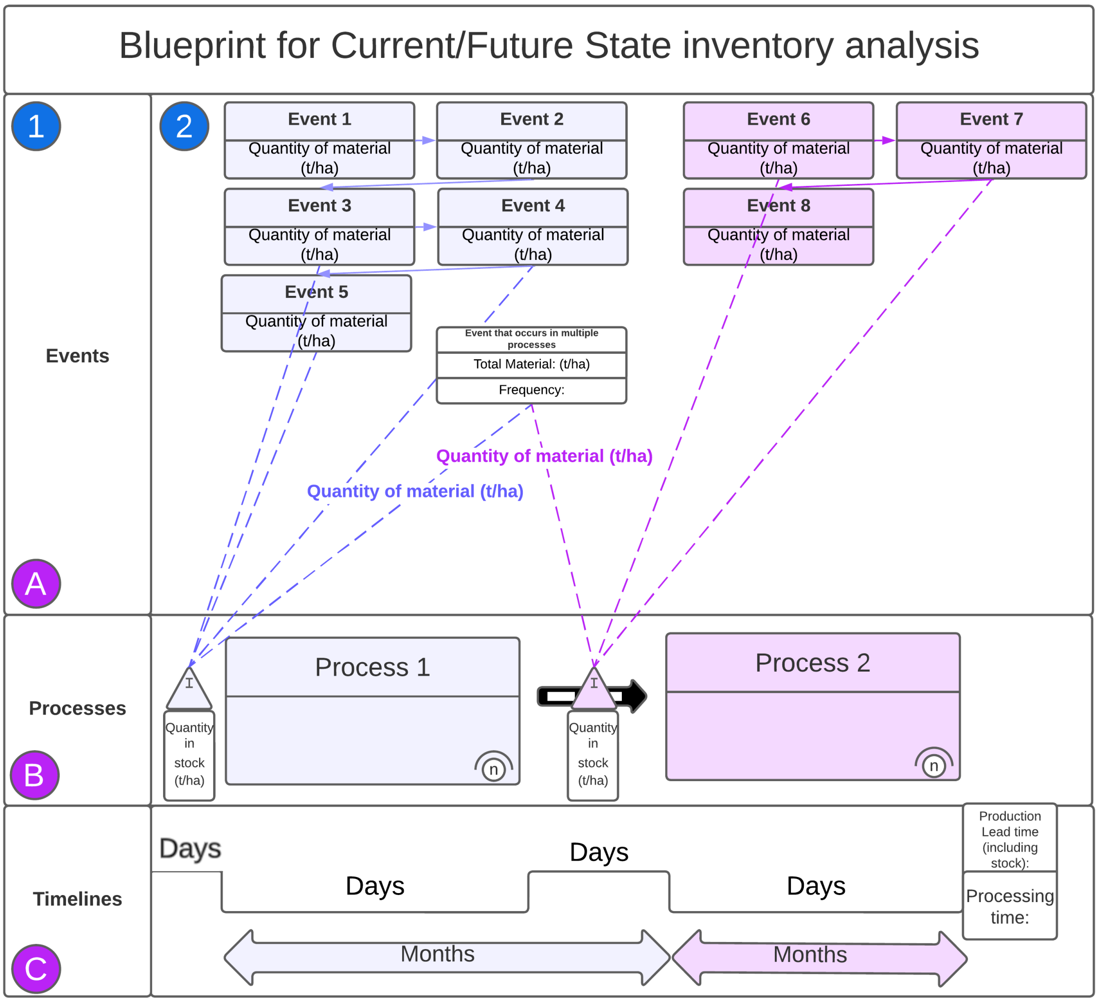
The model features two columns, labeled as 1 and 2. The first column pertains to the item labels found in the second column. Furthermore, there are three rows, denoted as A, B, and C, representing, in order, the events occurring within each of the processes, the processes themselves, and the timelines.

Figure 2: Current State and Future state diagram model for Sus-VSM application in farms.



Source: Author's own

Figure 3: Model for applying the blueprint inventory analysis for Current State and Future State



Source: Author's own

2.2. *The Sus-VSM application: step 4*

The farm (Figure 5) covers 73 hectares of planted area. It is in the Cabral Village at Salgado city. The workday consists of eight hours-day, with 22 working days per month. However, the work hours may vary due to climatic conditions requiring sometimes more workload per week. It's also worth noting that during the described period, the delivery of inputs to the farm occurred eight times (four times a year), with each delivery taking an average of seven days from the time of ordering to receipt. The delivery of harvested oranges (the final product) occurred into four deliveries: the first batch, for oranges with a poorer visual appearance, went to an orange juice producer, located almost 7 km from the farm, and the three others (with a better visual appearance) to a processing plant, located near 5 km from the farm, and subsequently following to local and big domestic markets. Figure 6 provides an overview of the most critical stages of the orange farm cycle, including images of various events within the farm's case study processes.

Figure 4: A drone-captured photo of the farm

Source: Author's own, picture from the farm.

Figure 5: Overview on the orange farm studied, including all processes

Source: Author's own, pictures from the farm.

Many data were collected based on the farm manager's experience and expertise. Some production activities take months or even years to occur, making it impractical to perform, for example, a time motion analysis to collect the cycle times for each process. An example of this is the orchard maintenance process, which, according to the farm management, lasted for 600 days (from planting the seedling to the first harvest of oranges). Additionally, the lack of predictability in agricultural production processes is a significant factor to consider, as this can vary depending on local weather conditions and the time of year (Andersson et al., 2020; Karyani et al., 2016; Melin and Barth, 2018). Therefore, most of the data presented in this case study are specific to the farm under analysis.

Furthermore, some data were collected during an on-site visit at the farm. This on-site visit provided complementary information such as the number of workers involved in the orange harvesting stage, the handling of the fruit for loading onto trailers and later onto trucks, the quantity of oranges harvested, and the equipment and machinery details employed.

Furthermore, some important considerations should be pointed out based on the interviews performed with the farm manager:

(i) In the Sus-VSM application, inputs for washing and lubrication of equipment (water and oil) are not explicitly shown in any part of the tool use. However, they are measured in the blueprint diagrams for stock analysis. This is explained due the presence of these events in all production processes and, for the sake of clarity in the value stream analysis they are only presented in the blueprint.

(ii) Some of the described activities on Sus-VSM do not have a standardized order and may depend on climatic conditions;

(iii) The washing time for machinery and equipment after a workday was standardized as 1 hour; to calculate water usage, it was assumed the amount of water used per wash (0.0045 t/ha or 330 liters) and the working days (considered that machinery is washed every working day, i.e., 22 days per month);

(iv) To calculate the amount of oil used per equipment, it was considered 9 liters of oil every 30 days, with a density of 0.9 kg/liter;

(v) For electricity consumption calculation, which is only used during machinery washing, the value of 1400 W or 19.18 W/ha was assumed, along with the number of working days in a month (22 days).

2.3. The Sus-VSM application: step 5

Finally, the following Lean & Green indicators and metrics were selected for the Sus-VSM application (Table I) and critical analysis of results. The set of proposed indicators and metrics were based on recent literature on the subject, such as De Oliveira Rezende *et al.*, (2022).

Table 1: Lean & Green indicators for the Sus-VSM application in agribusiness

Metric	Unit	Description	How to calculate
Climate Change	tCO_2e/ha	Emissions generated by the combustion of diesel used in tractors and trucks (related to Carbon Footprint).	Using the GHG Protocol spreadsheet (Brazilian GHG Protocol Program, 2008) and then divided by the number of hectares used in the process.
Energy	MJ/ha	Energy consumed in the execution of the process.	$\frac{\sum Energy\, used \in the\, process}{Hectares\, used \in the\, process}$
Material	t/ha	The quantity of raw material (input) needed to execute the process.	$\frac{\sum Energy\, used \in the\, process}{Hectares\, used \in the\, process}$
Waste	t/ha	The quantity of material wasted after the completion of the process.	$\frac{\sum Waste\, generated \in the\, process}{Hectares\, used \in the\, process}$
Water	t/ha	The amount of water used to complete the process.	$\frac{\sum Water\, used \in the\, process}{Hectares\, used \in the\, process}$
Land use	ha	The area utilized.	the number of hectares used in the process.

Setup Time (S/T)	h/ha	The time it takes to prepare and configure equipment before it is ready for use in production.	$\frac{\sum Process\ Setup \times ¿}{Hectares\ used \in the\ process} ¿$
Cycle Time (C/T)	h/ha	The total time to complete a task, from start to the next start of the same process.	$\frac{\sum Process\ Cycle \times ¿}{Hectares\ used \in the\ process} ¿$
Transport	$t*km^2$	The total distance traveled by tractor or truck.	$\frac{\sum Materials\ loaded\ by\ the\ trucks}{Hectares\ used \in the\ process}$
Performance per hectare	%	The relationship between waste generated and materials used.	$\left(\frac{Material - Waste}{Material}\right) \times 100$

Source: Author's own

Table 2 displays metrics to calculate the “OLGE” indicator (Overall Lean-Green Effectiveness). This is a new indicator proposed on this paper to summarize and combine Lean & Green results in the value stream. This is an adaptation of the classic OEE indicator (Chiarini and Gabberi, 2020) that can be calculated in a similar way as described on Table 2. However, the parameters ‘availability’ and ‘efficiency’ are substituted by ‘total performance per hectare’ and process ‘ecoefficiency’ as dependent variables.

Furthermore, VAT is the total Value-Added Time representing the sum of the cycle time (C/T) of each process under investigation (process 1 to process 5). This metric represents a part of the lead time (LT) necessary finalize the orange cultivation, harvesting and delivery to the market. A high %VAT lowers LT to aggregate more value in the value stream. It is noteworthy that the LT in agrobusiness be high because of the high amounts and variability of the required materials and activities.

Finally, OLGE is calculated by multiplying the %VAT by the total performance per hectare and the eco-efficiency index as can be seen in the Table 2. The main idea is to check which processes are reducing OLGE and how operational parameters could be optimized to enhance OLGE in the Future State of the farm. The high the OLGE the high the value aggregation and the lower the environmental impacts, as explained in the recommendations for interpreting OLGE in Table 3. The H1 reference situation is indicated to real present Lean & Green benefits in agribusiness.

Table 2: metrics to calculate OLGE

Metric	Unit	Description
VAT	Days	$\sum Cycle\,Time$
%VAT	%	$\frac{\sum Cycle\,Time}{Total\,Lead\,Time}$
Total performance per hectare.	%	$\left(\frac{\sum Materials - \sum Waste}{\sum Materials}\right) \times 100$
Ecoefficiency	%	$\frac{Total\,number\,of\,oranges}{¿¿}$
OLGE	%	$\%VAT \times Total\,Performance\,per\,Hectar\,e \times Ecoeff$

Source: Author's own

Table 3: general recommendations based on the proposed OLGE results

Hypothetical situation	Result	Recommendation
H1	Future OLGE is higher than the current state	Change to the future state. Where applicable, find additional practices to increase VAT, Performance and/or Eco-efficiency in the future state.
H2	Future OLGE is Lower than the current state	Review hypothetical scenarios to find other practices that can increase VAT and/or Performance in the future state, or increase Eco-efficiency, otherwise, maintain the current state

Source: Author's own

3. Results and discussion

3.1. *Sus-VSM on the Current and Future states*

Figures 7 and 8 depict, respectively, the Sus-VSMs of the current and future states from the application of the model on the study farm. This enabled the comparison of various metrics between the two states, as well as the identification of problems and their potential solutions.

To illustrate, in the Soil Preparation process, it was observed that soil analysis was carried out solely based on the farmer's experience. As a result, during the soil correction stage, the same amount of limestone was applied to all cultivated areas, potentially leading to overuse or insufficient input applications. In the future state situation, the solution involved a more precise evaluation through chemical, physical, and biological soil analysis.

Another problem was identified to three processes: Soil Preparation, Planting, and Orchard Maintenance. Weather variables were being assessed based on weather forecasts obtained from internet data sources. The solution proposed in the future state, on the other hand, involved the installation of meteorological stations close to the farm area to provide more accurate forecasts and facilitate the data analysis of climate issues.

Furthermore, it was identified that in the Planting process, there was a high mortality rate of orange seedlings shortly after planting. The fast solution was to switch to a different seedling supplier known for offering higher-quality products. By examining Figure 7 it can be observed the remaining issues, while Figure 8 illustrates the additional solutions that were identified. All the solutions were flow kaizens, i.e., simple and fast process solutions to enhance product added value. To support also minimizing environmental impacts, green indicators were adopted plus the OLGE results.

Table 4 quantitatively present the results for the current and future states through a comparison between the Lean and Green metrics for both states. Total C/T indicator was 78.2 to 75.72 h/ha, while the total setup varied from 2.10 to 1.48 h/ha, showing that S/T indicator was up to 2.68% of the cycle time in the current state and 1.95% in the future state scenario. Transport distances were relevant for the Soil Preparation and the was no changes comparing both the current and future states since the proposed value stream solutions (see Figure 8) did not cover transport waste.

Finally, the total performance per hectare showed that Soil Preparation resulted in 92.5% and the remaining processes performed better (up to 100%) because of lesser stocks mainly in the future state scenario. It’s important to note that in the future state, the utopia of zero waste in agriculture was considered.

In terms of green indicators, climate change impact was 0.152 and 0.046 tCO_2e/ha, respectively, in the current and future states, mainly associated with non-renewable use of fuels to operate tractors and trucks in the field, mainly during the Soil Preparation. In terms of material requirements (in t/ha), results showed that, for example, the reduction in the standard limestone application rate from 3 t/ha to 2 t/ha led to a decrease from 219 to 143 total tons of materials (34.70%). It's important to emphasize that the precise amount should be determined during the soil analysis step. Water and energy as green metrics were important to point out that by reducing the machinery washing frequency to once a week instead of once a day, there was 80.13% decrease in both water usage and energy consumptions. As a summary, the main hotspots were in the Soil Preparation because it generates most of the environmental waste and impacts and represents most of the opportunities of improvement for the future state.

Regarding Tables 5 and 6, they compare processing time for each of the farm processes, showing a decrease in time in three out of the five main processes in the value stream. This occurred primarily due to the hiring of a larger number of workers in the future state. The results showed that the added value (%VAT) from the current state to the future state grew from 9.77% to 13.85%. There was also 32.74% reduction in production lead time and 4.67% decrease in total processing time.

Table 4: comparison of Lean & Green Metrics for the Current and Future States

Metrics	**Soil Preparation**		**Seedling Care**		**Planting**		**Orchard Maintenance**		**Harvest**		**Weighing**	
	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future	Current	Future
Green Metrics												
Climate Change (tCO_2e/ha)	0.152	0.046	0	0	0.033	0.0099	0.414	0.1242	0.052	0.0156	0.028	0.0084
Energy (MJ/ha)	4.83	1.03	0.14	0.07	0.76	0.14	30.38	5.94	0.76	0.14	0	0
Material (t/ha)	3.52	2.53	0.124	0.123	1.23	1.23	0.68	0.528	0.055	0.0019	0.0005	0.00065
Waste (t/ha)	0.26	0	0	0	0.0023	0	0.01	0	0	0	0	0
Water (t/ha)	0.0315	0.0305	0.009	0.0045	0.0495	0.009	1.98	0.387	0.0485	0.009	0	0
Land use (ha)	73	73	1	1	73	73	73	73	73	73	0.02	0.02
Lean Metrics												
Setup time (S/T) (h/ha)	0.082	0.082	0.014	0.014	1.76	1.17	0.11	0.11	0.10	0.07	0.041	0.041
Cycle time (C/T) (h/ha)	10.41	10.41	0.22	0.22	1.5	1	60.16	60.16	5.9	3.93	0.0034	0.0034

Transport (t*km²)	186.51	186.51	0	0	65.7	65.7	23	23	32.85	32.85	675	675
Performance (%)	92.50 %	100%	100%	100%	99.81 %	100%	98%	100%	100%	100%	100%	100%

Source: Author's own

Table 5: comparison of Processing Time between the Current and Future States

Processing Time	Current	Future
Soil Preparation	95 days	92 days
Seedling Care	2 days	2 days
Planting	15 days	10 days
Orchard Maintenance	600 days	579 days
Harvest	15 days	10 days
Weighing	0.125 days	-

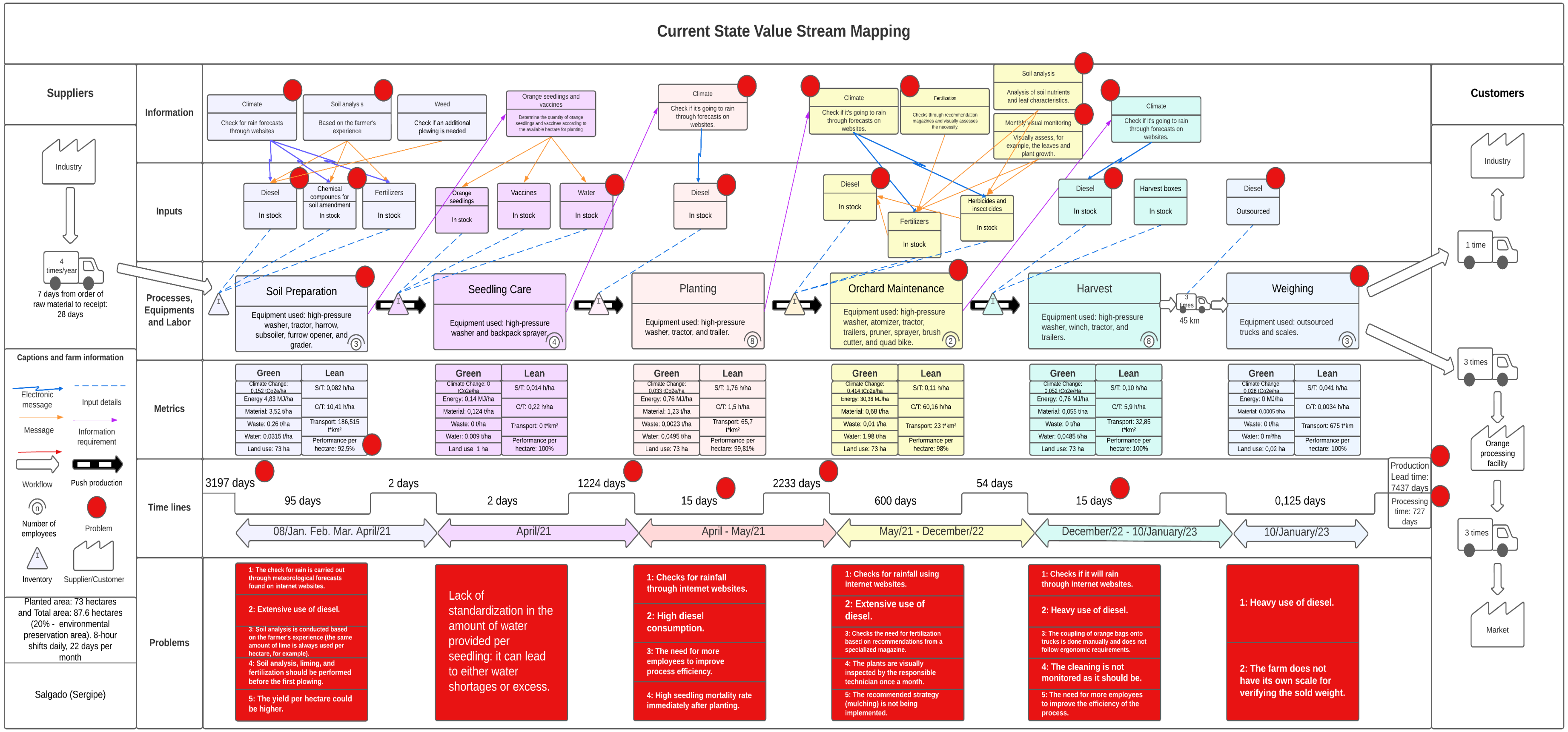
Source: Author's own

Table 6: comparison of Processing Time between the Current and Future States

Total times	Current	Future
Production Lead time	7437 days	5002 days
Processing time	727 days	693 days

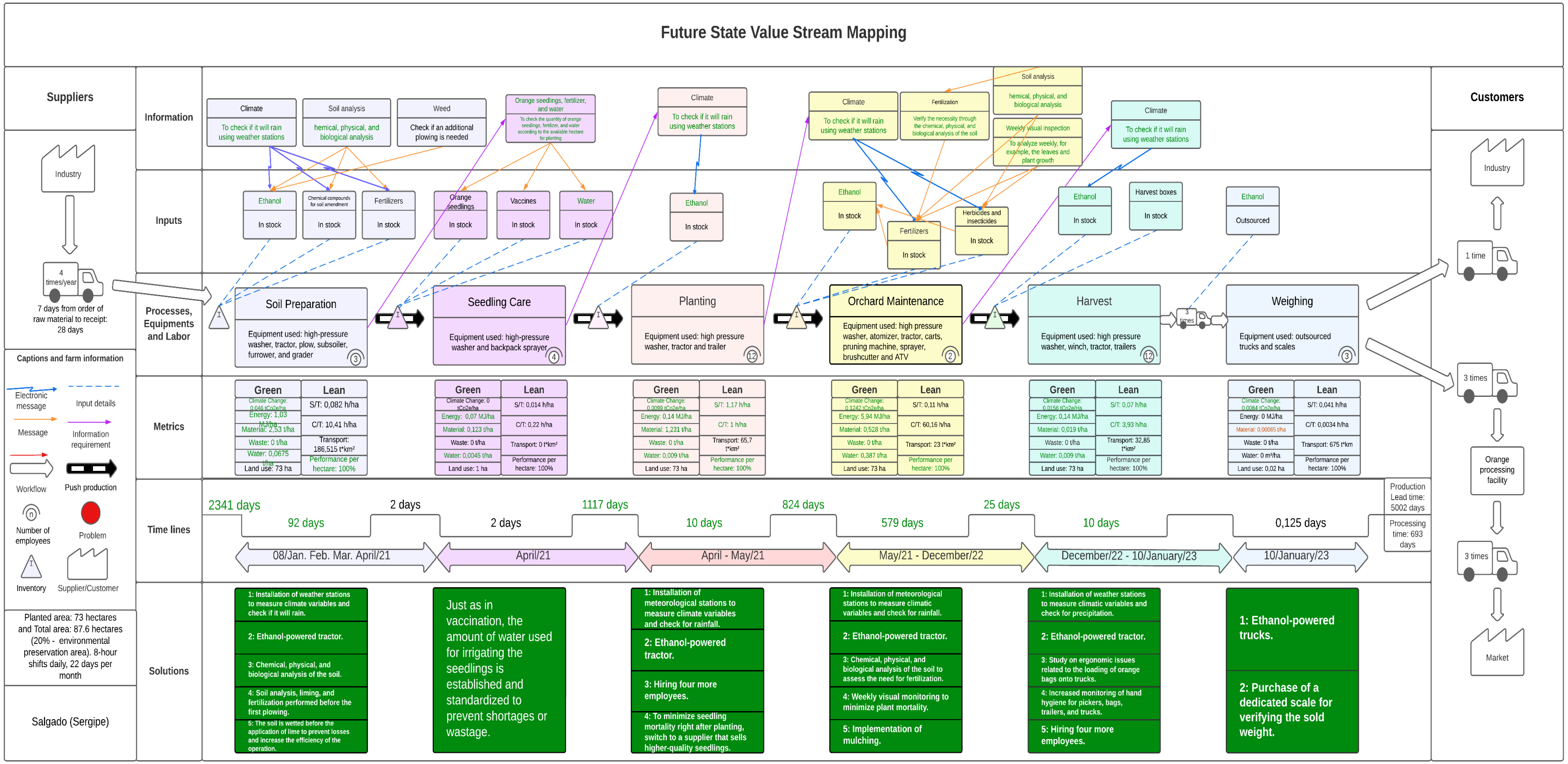
Source: Author's own

Figure 6: Current state VSM for the Case Study



Source: Author's own

Figure 7: Future state VSM for the Case Study



Source: Author's own

3.2. Blueprints for analysis of the stocks on the Current and Future states

Figures 9 and 10, respectively, present the blueprints for stock analysis in both the current and future states. By this, we were able to elaborate on and complement the Sus-VSMs allowing to depict the events constituting the processes and emphasize the influence of inventory on the final production lead time and VAT.

The inventory amounted to 7.58 t/ha or 6710 days in the current state and 4.91 t/ha or 4309 days in the future state, a reduction of approximately 35,78% in stocks. This reduction resulted from a decrease in water usage for washing, transitioning from daily to weekly. Furthermore, there was a decrease in limestone usage during the Soil Preparation, minimizing from 3 t/ha to 2 t/ha.

In Table 7 can be observed the total inventory before each process in units of days and t/ha of stocks, in addition to the relative comparisons between the current and future states. The Orchard Maintenance process was the most substantial in terms of less inventory (63.09%) in the future state. This occurred because it represents the longest-duration process with a high frequency of washing, leading to elevated inventory levels. In the future state, with a reduction in the number of washes, total stocks experienced a significant decrease followed by Harvest (53.70%) and by Soil Preparation with 26.77% reduction of stocks (chemicals and fertilizers).

It's noteworthy that Orchard Maintenance involves the most diverse and distinct inputs applied over time in the field, including three types of fertilizers, insecticides, fungicides, herbicides, and vaccines applications. Table 8 presents the inputs that appear in nearly all processes, encompassing fuel for tractors/trucks, machinery lubrication oil, and water for machinery washing. From this table, it is evident that there was an 80.12% reduction in the quantity of water used for machinery washing in the future state.

Furthermore, total inventory represents 90.22% of the total lead time during the farm's analysis period (2 years) in the current state and 86.14% in the future state. Therefore, even with the proposed improvements for the future state there is still a lack of deeper analysis of stocks for moving from pushing to pulling more the orange production. The results in the blueprint diagrams (Figures 9 and 10) should continuing assisting the farm managers to look for new ways of dealing with excess of inventory and serves as a simple and visual manner to track stocks and possible waste to be avoided.

Table 7: amount of stocks Stocks between the Current and Future States

Stocks before the	**Current**	**Future**	**Reduction**

process			
Soil Preparation	3197 days	2341 days	26.77%
	3.55	2.6	
Seedling Care	2 days	2 days	3.75%
	0.133 t/ha	0.128 t/ha	
Planting	1224 days	1117 days	8.75%
	1.359 t/ha	1.24 t/ha	
Orchard Maintenance	2233 days	824 days	63.09%
	2.48 t/ha	0.915 t/ha	
Harvest	54 days	25 days	53.70%
	0.06 t/ha	0.028 t/ha	
Weighting	-	-	-

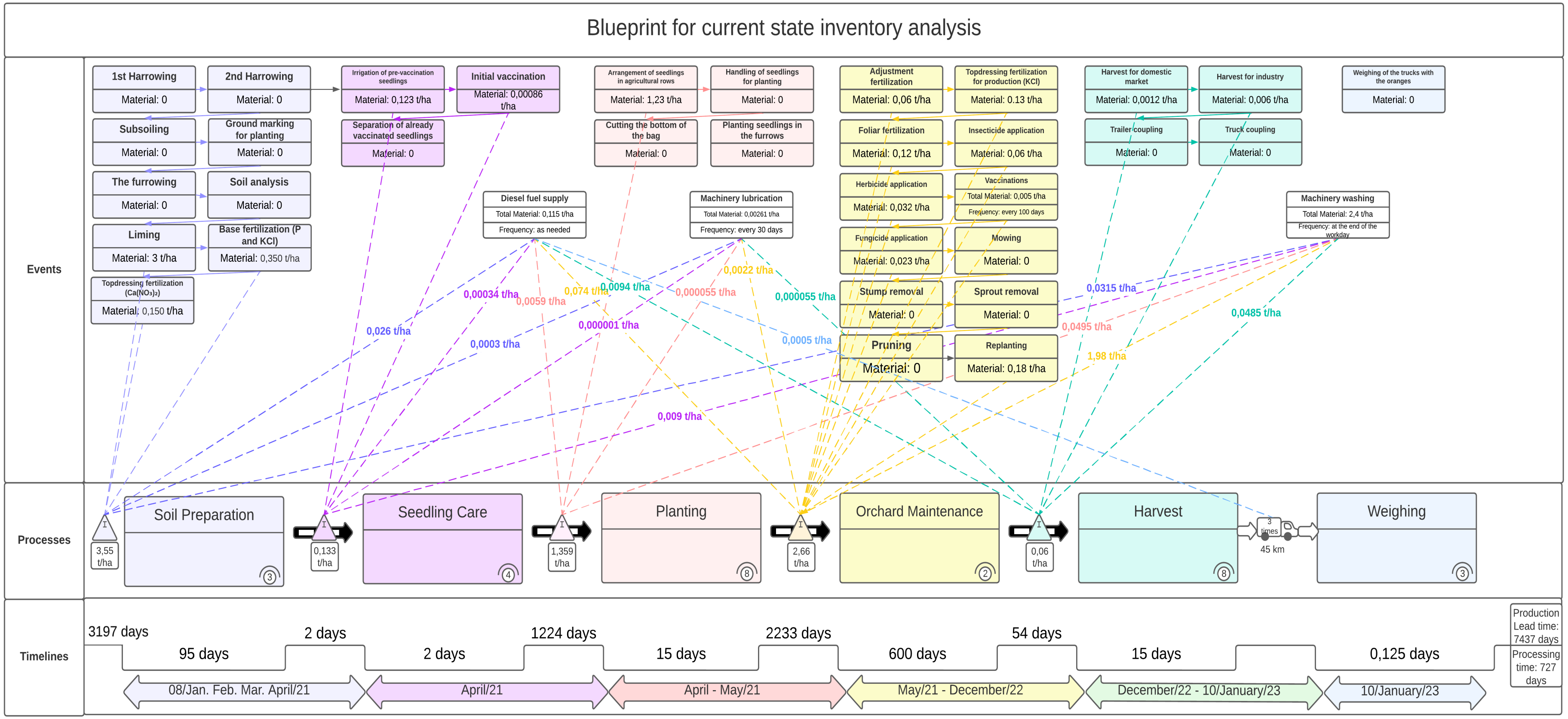
Source: Author's own

Table 8: comparison of inputs that appear in most processes in the Current and Future states

inputs	Current	Future
Fuel	Diesel	Ethanol
	0.115 t/ha	0.157 t/ha
Lubricating oil	0.0026 t/ha	0.0026 t/ha
Washing water	2.4 t/ha	0.477 t/ha

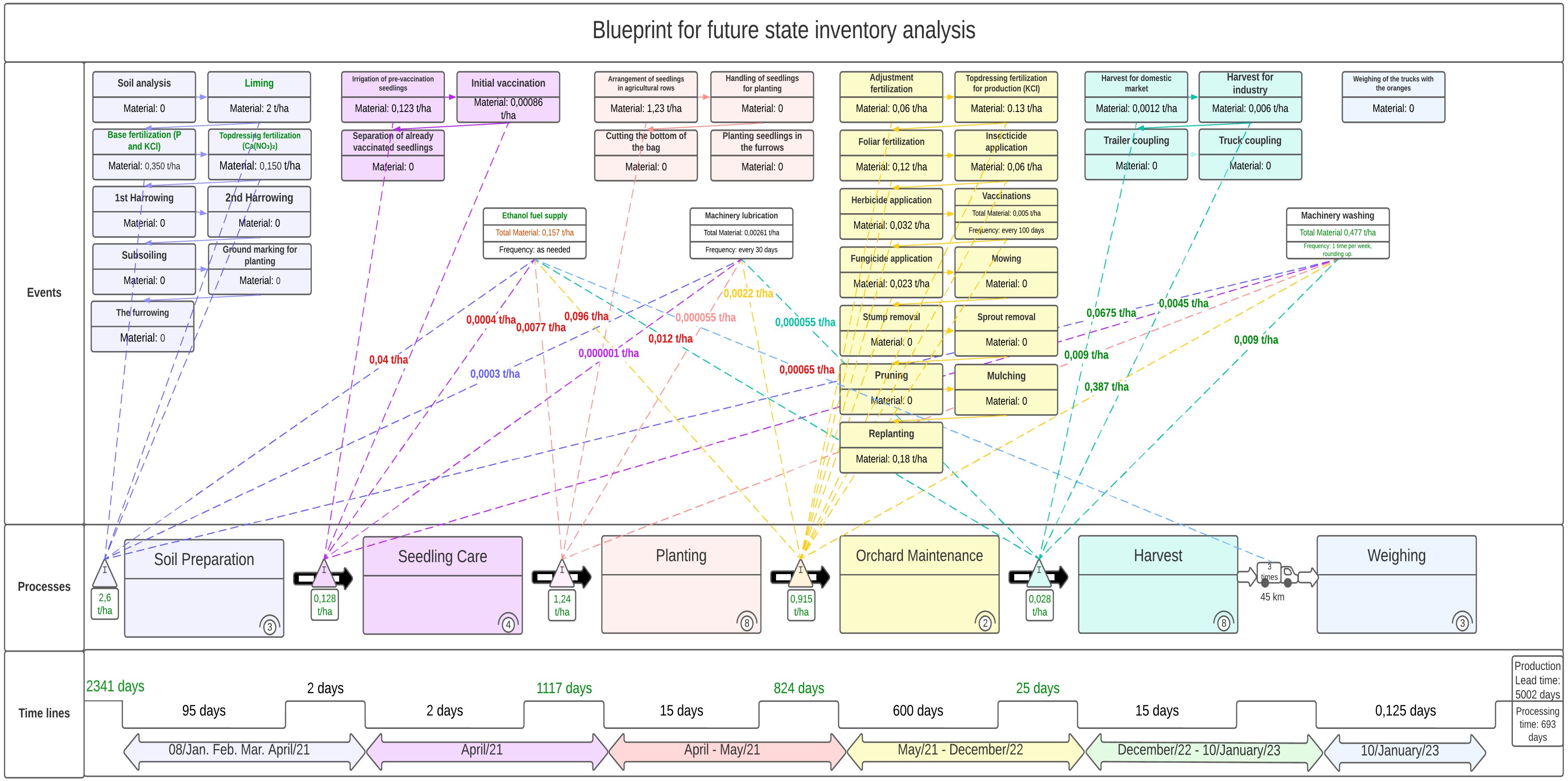
Source: Author's own

Figure 8: Blueprint for Current state inventory analysis



Source: Author's own

Figure 9: Blueprint for Future state inventory analysis



Source: Author's own

3.3. Interpretation of the Overall Lean-Green Effectiveness (OLGE)

The OLGE is derived from a composite calculation involving three key indicators: yield per hectare total (performance in %), added value time in the orange production (%VAT), and Eco-efficiency, as expl ained in Section 2.3. The first indicator quantifies the net materials/water that enter the system subtracting waste. The second indicator is rooted in the ratio of total cycle time to total lead time in the current and future states. Lastly, the third indicator assesses the total quantity of products (in this case, oranges) in relation to the quantity of materials/water that enter the system. A limitation is that climate change impacts can be not used to calculate OLGE as proposed on this paper, and a separate analysis of this green metric is required as discussed in Table 4. A next version of OLGE could include carbon footprint or greenhouse gas releases on the eco-efficiency calculations.

Just as with OEE, a classical metric for lean manufacturing systems (Marques et al. 2022), higher values of these three proposed parameters contribute to a greater OLGE result, signifying an improved/effective farm performance in terms of both Lean and Green principles. This global approach allows for a more holistic evaluation of agricultural practices considering sustainability and efficiency objectives in a simpler manner to assist decision makers on farms.

It's possible to view a comparison of the total OLGE indicator between the Current and Future states in Table 9. It is relevant to know that OLGE was far from 100%, as an ideal reference situation. This is because the proposed future state would still be pushing the oranges production instead of pulling farm activities. The blueprint diagrams show that a lot of stocks would be still creating high lead times reducing %VAT drastically. Also, eco-efficiency was almost doubled from the current to the future state, but it is still lower than the ideal 100% situation. This is because the lack of added value in the stream and the high levels of stocks affect the total amount of materials.

Table 9: comparison of OLGE indicator between Current and Future States

	Current	**Future**
Performance	95.15%	100.00%
%VAT	9.78%	13.85%
Eco-efficiency	7.99%	12.71%
OLGE	0.74%	1.76%

Source: Author's own

Likewise, literature about eco-efficiency in production systems is still few explored as reported recently by De Oliveira Rezende et al., (2021; 2022). Giusti et al. (2022) in a case study on the processing of chicken meat concluded that eco-efficiency can be improved based on changing diet production to chicken fattening. Also, Marques et al. (2022) have studied eco-efficiency in a beverage company and the results indicated that eco-efficiency could be increased if water content of a chocolate beverage is increased as well; these authors argue that the use of OEE lean indicator to calculate the beverage eco-efficiency does not fit a good way to combine both Lean & Green metrics. Then, to avoid this literature limitation this paper gives depth to the knowledge area by the proposition of the OLGE. This indicator is different because it uses eco-efficiency as a dependent parameter and not the opposite of that.

We believe the OLGE developed and applied on this paper could be adopted by similar systems to test the indicator use too. The OLGE is a hybrid indicator that combines Lean and Green metrics and is based on the OEE structure. But, different from the OEE itself, the OLGE is focusing on lean and green metrics by bringing eco-efficiency to the agribusiness in an holistic and simple way of application.

4. Conclusion and future research agenda

Based on what has been proposed, it can be concluded that the adaptation of the Current State and Future State based on the Sus-VSM and the creation of blueprints for inventory analysis were successfully carried out for improving the orange production as well as the measurement of the proposed Lean & Green indicators generated a more comprehensive view of the production flow towards a sustainable and lean management.

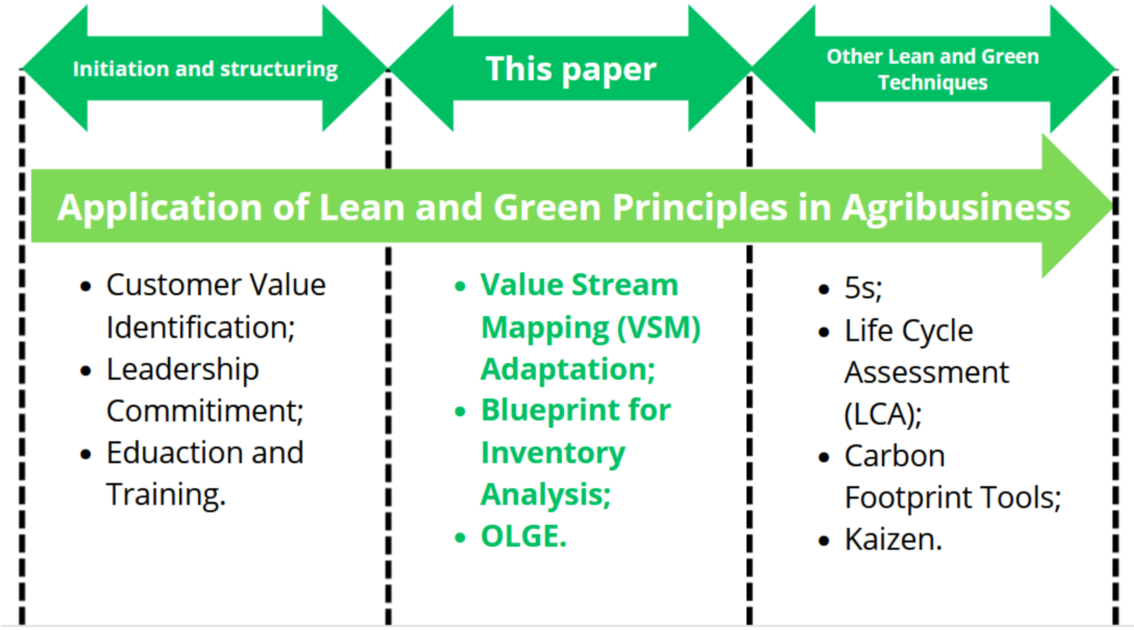
For example, in the case of the Soil Preparation stage, the potential for climate change in the current state was 0.152 tCO_2eq./ha, whereas in the future state, it decreased to 0.046 tCO_2eq./ha only. In the same stage, in terms of material consumption, the results showed a decrease of 28.13% from the current to the future state. In the Weighting stage, there was a 70% reduction in the potential for climate change too. Regarding water use, in the Orchard Maintenance phase, there was a decrease of 0.0395 t/ha from one state to the other. In the Planting stage, the time for replenishment reduced by 33.52%, and the cycle time was minimized by 33.33% from the current to the future state. Using the same metrics, but in the Harvesting stage, the reduction was 30% and 33.38%, respectively. To conclude the examples, in the Seedling Treatment stage, energy consumption decreased from 0.14 MJ/ha to 0.07 MJ/ha. All these benefits confirm the effectiveness of the Lean & Green developed framework implementation in the agribusiness agenda.

Additionally, the results showed that the %VAT from the current state to the future state increased from 9.77% to 13.85%, the yield per hectare was upgraded from 95.15% to 100% as waste was eliminated by the set of solutions planned to be implemented for the future scenario, taking into account the mentioned utopia. Eco-efficiency results were maximized from 7.99% to 12.71%. From this, it is possible to observe that the OLGE would be increased from 0.74% to 1,76%.

The low values of %VAT and eco-efficiency indexes reduce OLGE indicator, and the proposed case study exemplifies the difficulty of implementing lean-green practices within the agribusiness sector and underscores the significant potential for enhancement if a better management of stocks in the field could be possible to develop. There is substantial scope for optimizing the value flow to increase the percentage of VAT and for bolstering environmental performance to elevate eco-efficiency. The stocks should be enhanced in the future based on the blueprints of stocks developed on this paper, as it serves as a good and fast way to analyze and monitor the processes in the field with more needs of inventory management. In conclusion, OLGE in the orange production case was very dependent on the stocks management.

To facilitate and simplify understanding, in which stage are the activities carried out in the present article located, Figure 4 schematically presents a proposal for the application of Lean and Green tools in agribusiness, divided into three stages: initiation and structuring, what this article covered, and other Lean and Green techniques to complement the study.

Figure 10: The proposed structure to build Lean & Green VSM in agribusiness activities



Source: Author's own

Finally, five recommendations for future research were identified:

(i) The creation and application of a Lean framework with a sustainability perspective that includes the tools addressed in this study, in more applications on the topic;

(ii) The utilization of the Climate Change and Energy metrics to explore a possible new version of OLGE;

(iii) Development of a dynamic VSM using system simulation software (Aprillya, Mala Rosa; Suryani, Erma., 2023).

(iv) Incorporating social and financial aspects into the tools used (Alzubi, Emad. *et al.*, 2024);

(v) Perform the analyses including planetary boundaries (Hoogstra A.G. *et al.*, 2024).

Acknowledgments

This work was supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) under grant 150662/2022-0, the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), under grant 2022/04286-5, and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) - Finance Code 001.

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