Modelling the Risk Susceptibility of Agro-Industry Circular Supply Chain During Major Disruptions: A Life Cycle Perspective

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Abstract

The agro-industry is one of the main contributors to the food supply worldwide. Thus, the importance of its supply chain activities (i.e., harvest to fork) is crucial and should not be affected by any delays. However, inevitable disruptions may have an adverse impact on the supply chain activities in the agro-industry, such as natural disasters, climate change impacts, health crises, and technological lags. These risks must be appropriately mitigated considering the fragility and sensitivity of agricultural products to various factors (e.g., temperature, time). However, an assessment for agro-industry risk susceptibility remains unexplored in the literature. Thus, this study intends to assess the aversion of the agro-industry to such disruptions through conditional value-at-risk (CVaR) based risk control. A life cycle perspective will also be utilized to obtain a systematic view of the circular supply chain. The methodology used will be in two folds: (1) calculate the CVaR variable in the agro-industry supply chain and integrate it to the (2) life cycle assessment of agro-industry circular supply chain using the data collected from existing literature. The integrated methodology is utilized in the cassava starch production. The findings of the study show that the average loss at worst 10% volatile price is 15.22%, at worst 5% volatile price is 22.62%, and at worst 1% volatile price is 33.94%. Furthermore, the environmental impact assessment conducted revealed that the acidification has the highest kg-equivalent in terms of the environmental impact of the cassava starch production. Machineries and equipment utilized in the current production process of cassava starch has contributed immensely to the adverse impact on the environment, specifically in the acidification due to emissions.

Keywords
agro-industry, risk, life cycle perspective, modelling, circular supply chain

1. Introduction
The agriculture industry contributes most food products (e.g., staple products, baked goods, beverages, nutritional drinks, among others) worldwide. The significant role of agriculture in providing food for consumption was

highlighted when it met the rapid demand of the increasing population between the early 1960s and the late 1990s (Alexandratos & Bruinsma, 2012). Thus, the emergence of the agro-industry concept, an industrial activity that utilizes agricultural products as raw material, designs, and provides equipment and services, became widely accepted in the industry and academe (Afrianto et al., 2020). Various works in the literature have emphasized the importance of the agro-industry supply chain due to the importance of its end product (e.g., Gardas et al., 2018). Consequently, it should be noted that delays for the entire supply chain of food products should be minimal. An assessment of risk susceptibility of the agricultural supply chain has been highlighted by (Leat & Revoredo-Gha, 2013). Although there are studies that identify the risk involved in the agro-industry chain (e.g., Leat & Revoredo-Gha, 2013; Azizsafaei, 2021), a systematic assessment of these risks remains to be unexplored in the domain literature. Other than that, economic, environmental, and social factors such as globalization, technological innovations, trade agreements, consumer awareness, and environmental concerns also play a significant role in the global supply chain for agricultural products (Dinu, 2016). Furthermore, the global population is projected to reach 9.70 billion, and food production is estimated to rise 59-98% by the year 2050 (Elferink & Schierhorn, 2016). Thus, maintaining an efficient, sustainable supply chain for agricultural products is essential to meet future demand.

To maximize outputs in the food industry and minimize supply chain risks, various studies from the literature have explored the efficiency of agricultural production through the internet of things (e.g., Mirani et al., 2019), imaging techniques (e.g., Yaqoob et al., 2021), blockchain technology (e.g., Afrianto et al., 2020), among others. Despite the emerging technologies, there are inevitable instances that post-harvest, harvest, production, and delivery of such products will be affected by significant disruptions. These disruptions include natural disasters, climate change impact, health crises, and technological lags and are not only limited to the agro-industry. Considering the complexity and interrelationships of the key players in the agro-industry supply chain, the adverse impact of these disruptions may not only affect agricultural production but also post-production activities. Most importantly, food products are easily damaged, while logistically handling these products requires utmost care. Guan et al. (2011) emphasizes the unique characteristics of the food supply chain compared to other types due to the following reasons: (1) longer and more complex factors, (2) stricter supervision of production time, storage, and transportation, and (3) its inherent strong commonality and sociality. Given the fragility and sensitivity of agricultural products, such unprecedented delays should not be present and adequately mitigated.

The importance of assessing the risk susceptibility of a supply chain is apparent. However, the assessment of risk in the agro-industry remains to be unexplored. Thus, this study intends to develop a systematic assessment of the risk susceptibility of the agro-industry supply chain, especially during a significant disruption using conditional value-at-risk (CVaR) based risk control variable. Furthermore, a life cycle perspective will be integrated in the assessment to consider the entire impact of the agro-industry supply chain. One of the rising approaches in supply chain management is the life cycle assessment (LCA), which involves a cradle-to-grave assessment of a specific product. Furthermore, LCA determines the most effective improvement strategies and avoid burden shifting from one environmental impact to another (Hellweg & Milà i Canals, 2014). LCA is a widely adopted methodology in the domain literature wherein its application to various sectors includes wine (Ferrara & Deo, 2018), municipal solid waste (Khandelwal et al., 2019), transportation (Patouillard et al., 2020), energy (Benou et al., 2016), construction (Lasvaux et al., 2015), polymeric (Blanco et al., 2020), among others. To further capture the environmental impact of the agro-industry supply chain, this study also intends to evaluate the effect of the circularity of the supply chain through LCA. Circular supply chain consists of the forward and backward logistics in an integrated industrial ecosystem to produce a specific product or service (Batiste et al., 2018) and remains to be highly relevant in advancing the concepts in green and sustainable supply chain. Thus, this study aims to develop a risk assessment for the agro-industry circular supply chain through a life cycle perspective amidst major disruptions. The main departure of this study involves generating design initiatives that are beneficial to the academe and industry for risk response during a major disruption in the agro-industry. The paper is structure as follows: Section 2 discusses the materials and methods involved in the study; results and discussion are in Section 3; and the conclusion is remarked in Section 4.

1.1 Objectives

This study aims to model the risk susceptibility of agro-industry supply chain during major disruptions through a life cycle perspective. Specifically, this study will realize the objective through the following:

- Determine the risk susceptibility of an agro-industry supply chain
- Executive a life cycle assessment of an agro-industry circular supply chain
- Integrate the risk susceptibility model to the life cycle assessment

- Conduct a life cycle interpretation

2. Methods

The general methodological flow utilized in this study is illustrated in Figure 1. As shown, the first step consists of the supply chain risk assessment. A determination of the supply chain risk in agro-industry using a literature survey. A list will be developed, and a mathematical formulation of the risk will be done using the CVaR-based risk control model. On the other hand, the life cycle model formulation will be done first by defining the goal and scope of the model. After that, a life cycle inventory will be completed, and the life cycle impact will be assessed. This model formulated will then be integrated with the CVaR-based risk control variable. After the integration, a life cycle interpretation will be executed to design initiatives in mitigating the risk of supply chain disruption in the agro-industry.

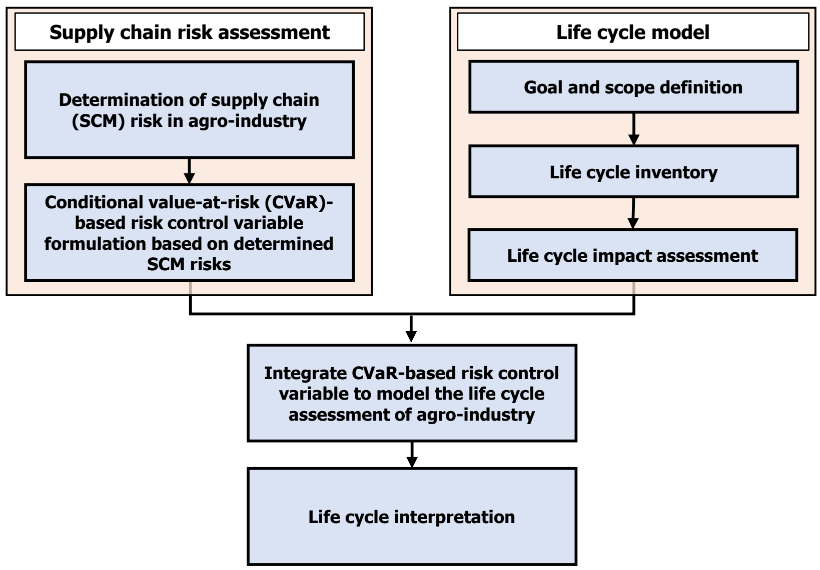

Figure 1. Life cycle impact assessment with an integrated CVaR-based risk control variable methodological framework.

2.1 Supply chain risk assessment

The supply chain risk considered in this study is the price volatility of commodity (Jaffee et al., 2010). Data collected are from the Food and Agriculture Organization (FAO) database (2022). This supply chain risk will be modelled using the CVaR-based risk control and is discussed as follows:

Let $g(x, y)$ be the agricultural supply chain risk function and $x, x \in X$ as the supply chain risk factor. The feasible combination of controls for the supply chain risk factor is X. Furthermore, y represents the loss value of the supply chain risk, $y \in R^n$. When y is a random variable, which has a known distribution and a critical value α, and the loss goes beyond the critical value at the confidence level θ, the conditional expectation loss value of the loss function under the condition of loss that goes beyond $\theta - VaR$ is obtained. On the other hand, if n types of risk occur in the future, the loss ratio of m types of risks during n period in the past is obtained by the estimation of the loss value of the supply chain risk through a scenario analysis. The value of y in each case is $y^k(k = 1,2, \dots, n)$. With $x^T = (x_1, \dots, x_m)$ representing capital distribution under m types of supply chain risk controls, $x \in X$ and $x \subset R^n$, the feasible control combination for the supply chain risk factors is X. Thus, minimization model, as adapted from Yan et al. (2014), is formulated as follows:

$$\min\left((1-\theta_i)^{-1}\sum_{k=1}^{n}\left(g_1(x,y^k)\right)^+, \dots, (1-\theta_I)^{-1}\sum_{k=1}^{n}\left(g_I(x,y^k)\right)^+\right) \quad (1)$$

such that

$$\sum_{i=1}^{m} x_i = 1 \quad (2)$$

$$0 \le x \le 1 \quad (3)$$

The parameters of the CVaR-based risk control model are as follows:
x – supply chain risk factors
X – feasible combinations of controls for the supply chain risk factors
y – loss value of the supply chain risk
$g(x, y)$ – agricultural supply chain risk function
θ – critical value at the confidence level
n – number of risks in the future
m – number of risks in history
y_i^k – loss ratio of risk i during period k
w_i – average losses of risk i occurrence during period k

2.2. Life cycle model

The LCA study has been conducted following the guidelines provided by the ISO 14040/44 (ISO, 2006). The assumptions and data are detailed and discussed as follows: goal and scope, inventory data, and impact assessment.

2.2.1. Goal and scope

The aim of this study is to model an agro-industry (i.e., cassava starch production) through life cycle impact assessment with an integrated CVaR-based risk control variable. This study is focused on the production and logistics process in the agro-industry, as illustrated in Figure 2. As shown in the figure, six (6) processes are involved in the cassava starch production. The production process includes peeling of the roots, washing, grating, sieving, sedimentation and sun-drying. Furthermore, the system boundary considered in the study is a from-cradle-to-farm-gate perspective (see Figure 2). The process of converting residues from the sieving and sedimentation process into animal feed is also included in the system boundary. This will serve as the process that involves the circularity of the production process.

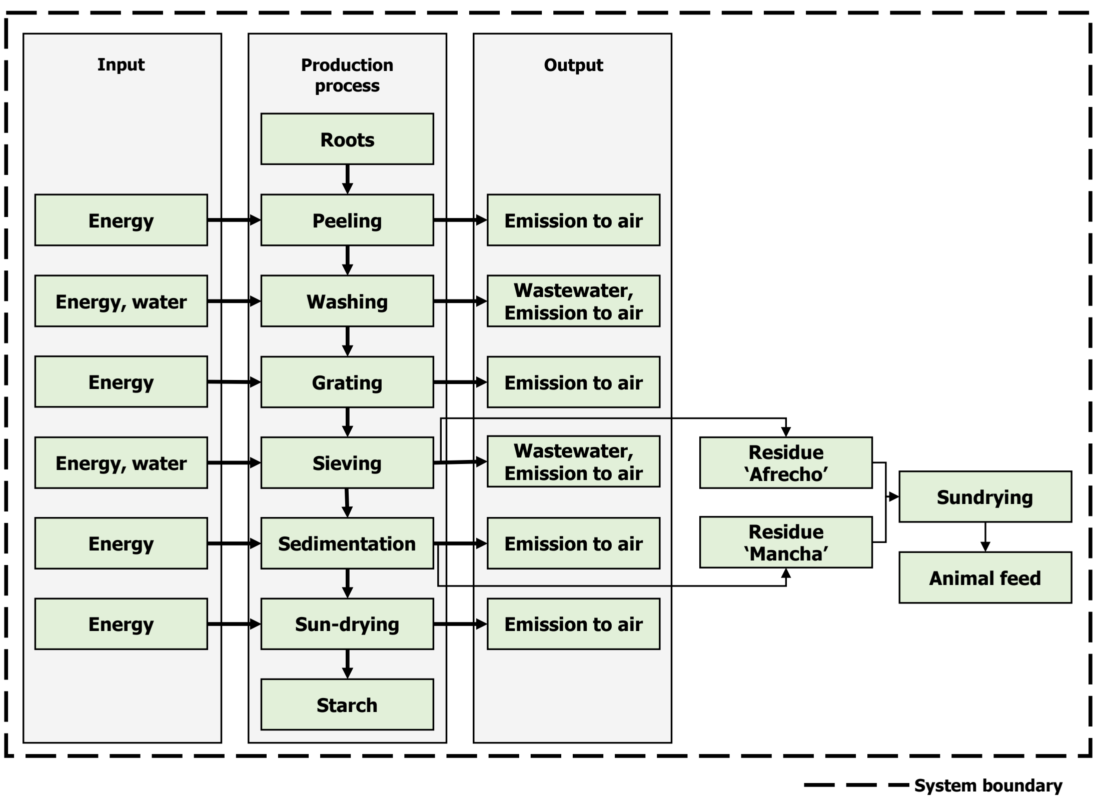

Figure 2. System boundary for cassava starch production.

2.2.2. Inventory data

The functional unit utilized, as used mostly by agricultural LCAs, is the crop production. The inventory data is collected and organized from the literature and relevant LCA databases. The data sources (i.e., input and output) is presented in Table 1 while the secondary data required to convert resources input into their energy equivalent is presented in Table 2.

Table 1. Inventory data of cassava starch production (Olaniran et al., 2017).

Parameters	Measurement unit	Values per 1000kg of cassava
Diesel	MJ	3.942E+02
Stationary engines	MJ	9.180E+03
Coal	MJ	3.879E+03
Emission from fuel combusted		
CO_2	kg	7.883E+02
CH_4	kg	0.122E+00
N_2O	kg	2.167E-03
Emission from stationary engines		
CO	kg	2.199E+00
SO_2	kg	4.272E+00
NO_x	kg	1.876E+00
Emission from coal		
CO_2	kg	1.025E+04
SO_2	kg	4.187E+00
Product		
Starch	kg	3.120E+02

The process flow for the cassava starch production is adapted from Wheatley et al. (2003). Furthermore, the description and specifics of the production process is obtained from their work. The first step in the production process involves the washing and peeling of cassava roots, wherein 3-5 m^3 of water is used for the washing process. To attain the starch granules, the roots are then grated. The starch is further extracted under running water at an amount of 8-12 m^3. After that, the fiber and other root components are separated from the starch by sieving. Solid starch is then obtained by sedimentation or centrifugation. The resultant starch is sundried to a final moisture content of 12–14%.

3. Results and Discussion

Using the food price index from the FAO database (2022), the CVaR value for agro-industries are calculated as follows:

Table 2. CVaR value for risk susceptibility of agro-industry supply chain.

Confidence level	CVaR
0.90	-15.52%
0.95	-22.62%
0.99	-33.94%

Based on the results presented in Table 2, in the worst 10% volatile price, the average loss would be at 15.22%. Likewise, in the worst 5% volatile price, the average loss would be at 22.62%. Lastly, in the worst 1% volatile price, the average loss would be at 33.94%. The consideration of the price volatility includes the uncertainty during the COVID-19 pandemic in the years 2020-2022. This uncertainty of the supply chain may have contributed to the high value of average loss. Aside from that, climate change has attributed to crop reduction and uncertain price hikes in food commodities.

Considering the risks in the agro-industry supply chain due to price volatility at 0.90 confidence, the assessment of the life cycle inventory for the said industry yields the following environmental impact:

Table 3. Characterization results for emissions in the production of cassava starch.

Environmental impact category	Emissions	Units	Amount (kg)
Global warming	CO_2	kg CO_2-equivalent	-3.98E-13
	CH_4	kg CO_2-equivalent	-5.55E-17
	N_2O	kg CO_2-equivalent	-7.59E-19
	CO	kg CO_2-equivalent	8.88E-16
Acidification	SO_2	kg SO_2-equivalent	2.03E+01
	NO_x	kg SO_2-equivalent	8.92E+00
Eutrophication	NO_x	kg NO_3-equivalent	8.92E+00
	N_2O	kg NO_3-equivalent	-7.59E-19

As shown in the results, acidification is the environmental impact that yields the highest kg equivalent. It is then followed by eutrophication and global warming, respectively. Thus, a large contribution to the adverse environmental impact was due to emissions caused by the machinery and equipment used in the cassava starch production. Certain measures must be initiated by key policymakers in order to mitigate the problem. Furthermore, other sustainable practices for the production process can be adapted by the industry, such as converting the residue into biogas. (Table 3).

To assess the robustness of the integrated model, a sensitivity analysis is conducted. The following confidence intervals of the CVaR value are considered in assessing the environmental impact of an agro-industry: 0.90, 0.95, 0.99. The environmental impacts from the various CVaR values are compared (Figure 3) as part of the sensitivity analysis.

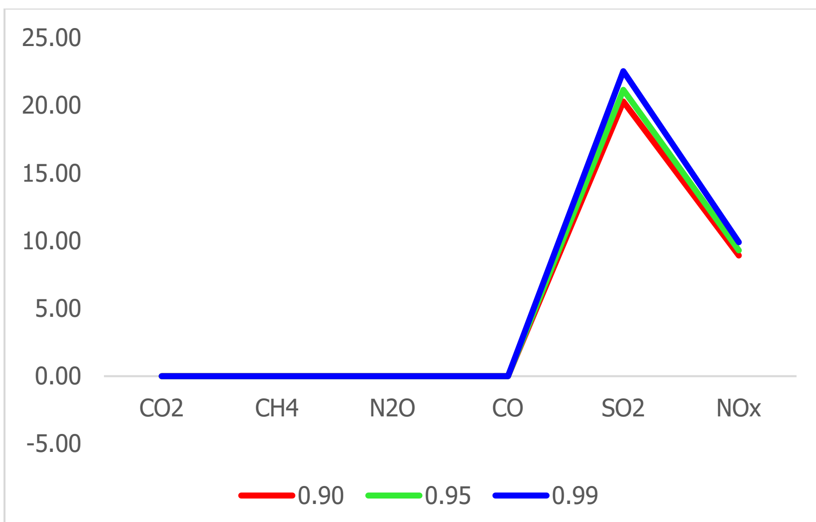

Figure 3. Comparison of environmental impacts of the three confidence intervals (i.e., 0.90, 0.95, 0.99).

As shown in the figure 3, the amount in kg-equivalent of the six environmental impacts (i.e., CO_2, CH_4, N_2O, CO, SO_2, NO_x) does not differ despite the varying confidence intervals. It is apparent that the integrated model, at different confidence intervals yields the same result. Thus, the integrated model is robust.

3. Conclusion

This work integrates the risk susceptibility of agro-industry supply chain in assessing the environmental impact of the said supply chain through a life cycle perspective. To measure the risk of the agro-industry supply chain, the CVaR model is utilized. The risk considered in this study is the price volatility of the food commodity. Results show that the average loss at worst 10% volatile price is 15.22%, at worst 5% volatile price is 22.62%, and at worst 1% volatile price is 33.94%. This risk-based assessment is integrated into LCA to model cassava starch production. The findings revealed that acidification has the highest kg-equivalent in terms of the environmental impact of cassava starch production. The limitation of this study includes the process in the production considered in the circularity of the supply chain. The output of closed-loop process (i.e., sun drying residues 'Anfrecho' and 'Mancha') did not contribute to any other process in the cassava starch production. Aside from that, only one supply chain risk was considered (i.e., price volatility of the commodity). For future work, other process integrated for the circularity of the agro-industry supply chain should be considered. Such process includes the use of production residues as energy sources. By using the residues as an energy source, the environmental impact of the production process will be minimized. Furthermore, other models in measuring the supply chain risk in agro-industry should be utilized. Aside from that, various risks of the agro-industry supply chain such as loss of product quality due to logistical breakdown, and adverse weather disrupting production should also be considered.

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Biography

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