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# KERANGKA KERJA SUSTAINABLE SUPPLY CHAIN RISK MANAGEMENT INDUSTRI KELAPA SAWIT DI INDONESIA

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**ABSTRACT**
Abstract This paper combines three main concept including supply chain management, sustainability and risk management which is put palm oil Industry in Indonesia as an object. It explores sustainability-related supply chain risk from principle and criteria of roundtable sustainable palm oil (RSPO) and Indonesian sustainable palm oil (ISPO), distinguishes them from common supply chain risks and develop framework for their management. 45 risks across the three main pillars of sustainability (environmental, social, economic/financial) are identified from extensive review from principle and criteria of RSPO and ISPO. The fuzzy failure mode and effect analysis (fuzzy FMEA) approach is utilized to assess the relative importance of 45 risks. Based on the findings of the study, risks response and treatments are proposed for each sustainability-related supply chain risks. The findings show generally three most important risks are low OER (oil extraction rate), FFB (fresh fruit bunch) looting, un-fulfill palm oil mill capacity, respectively. Finally, integrated sustainable supply chain risk management approaches need to implement by the management of palm oil industry.

## Introduction

Indonesia as the largest producer of palm oil in the world, the volume of exports of palm oil and its derivatives did increase significantly from year to year, where in 1981 amounted to 196,361 tons, increased to 1.16 million tons in 1991, increased again to 4.9 million tons in in 2001 and became 16.4 million tons in 2011, then touched 26.15 million tons in 2015 (Directorate general of estate crops, 2016). The palm oil industry is an important industry for Indonesia, most recently an increase in exports of palm oil products and their derivatives by 8% from 2017 by 32.18 million tons to 34.71 million tons in 2018(Directorate general of estate crops, 2016). The value of foreign exchange generated by Indonesian palm oil is also quite high, where in 2017 it reached 22.97 billion US dollars and in 2018 it reached 20.54 billion US dollars(Gapki, 2018).

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The palm oil industry faces major challenges related to sustainability due to several issues including food chain disruption, conversion of peatlands(Khatun, Moniruzzaman, & Yaakob, 2017). In addition, this industry is also associated with conflict over land tenure, emission of greenhouse gases, and biodiversity loss (Moreno-peñaranda et al., 2015). European Union as the second largest market for Indonesian palm oil through the European Union delegation to Indonesia in 2019 even said that palm oil is associated with the highest level of deforestation, where in the period 2008-2015 45% of palm oil expansion was in high carbon stock areas(Delegation of EU to Indonesia, 2019). According to the report, the European Union wants to ensure that regulations are needed to ensure that the raw material for biofuels used in EU countries must be sustainable and that it does not cause deforestation through indirect land use change (ILUC) (Delegation of EU to Indonesia, 2019). In an earlier press release, April 2017, the European Parliament proposed a ban on the use of unsustainable palm oil for biofuels on the EU market in 2020 (EU Commission, 2018).

Great pressure on the palm oil industry has actually been attempted to be alleviated through the implementation of sustainability certification in advance through the RSPO and ISPO. The Roundtable on Sustainable Palm Oil (RSPO) is an alliance of key actors throughout the palm oil supply chain including large producers, smallholders, processors, traders, NGOs and certifiers among them with the aim of promoting sustainable production and consumption of palm oil in 2003(RSPO, 2013). In addition to the voluntary RSPO, Indonesia specifically applies ISPO which is mandatory for the palm oil industry in Indonesia. Indonesian Sustainable Palm Oil (ISPO) is the most important government regulation relating to the palm oil industry in Indonesia. The ISPO was issued by the Ministry of Agriculture in 2011 as a commitment of the Indonesian palm oil industry to sustainability with the aim of increasing the competitiveness of Indonesian palm oil on the world market and also fulfilling the promise of the president of the Republic of Indonesia to reduce greenhouse gas emissions and reduce the impact on confusion (Joviani & Lovett, 2019).

Sustainability was originally defined as a meeting between meeting current needs without affecting future generations with regard to social, economic, and environmental responsibility (Hou, Wang, & Xin, 2019). The big challenges in implementing sustainability in the palm oil industry supply chain certainly have risks of failure and require large funding, therefore the Supply Chain Risk Management (SCRM) needs to be applied. SCRM is a tool that has mechanisms to asses and separate risks with the intention that these risks are passed at a lower cost (Wu and Blackhurst 2009, Giannakis and Papadopoulos 2016). These risks, if managed properly, the costs used will be lower.

SCRM itself has been highly developed in the last two decades due to several reasons including (1) globalization which causes supply chains to become longer and more complex, (2) lean management philosophy which is widely applied in many industries, (3) the world gives a lot of attention to supply chain disruptions(Behzadi, Sullivan, Olsen, & Zhang, 2017). However, the development of SCRM has not been implemented in the case of the palm oil industry in Indonesia. This research tries to offer a sustainable supply chain risk management framework that is specific to the palm oil industry in Indonesia. The Fuzzy FMEA (Failure Modes and Effect Analysis) method is used as an analysis tool. Fuzzy FMEA generally uses an if-then approach to prioritize, which requires basic rules based on expert judgment. For subjective approaches and undefine experts judgement, the use of fuzzy linguistics is appropriate (Kirkire, 2015). Fuzzy linguistic is used in this study.

In general, the objectives of this study include:

To identify sustainability-related risk in supply chain of palm oil industry in Indonesia.

To prioritize sustainability-related risk in supply chain of palm oil industry in Indonesia.

To create risk response and treatments

To develop sustainable supply chain risk framework of palm oil industry in Indonesia.

The paper proceeds as follows. Section two literature review. Section three details the methodology. Section four discussed sustainability-related risk identification, ranking and analysis using fuzzy FMEA. Risk treatment and mitigation are presented in section five. Finally, section five develop framework and draws conclusion.

## LiteratureReview

### Sustainable Supply Chain Management

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Supply chain has been a familiar concept since the early 1980s among practitioners and academia (Martins & Pato, 2019). Supply chain describe as a combination of organization ,people, technology, activities, information, and resources in a system that involved into the function of procurement and transformation raw materials into work-in-process and finished product that delivered to customer (Ghane & Tarokh, 2012). Supply chain management has a strategic impact to any business activity and corporate (Golrizgashti, 2014). Oliver and Webber (1982)  defines SCM as a technique for reducing stock owned by companies that are in the same supply chain. SCM is essentially the integration of supply and demand both inside and outside the company, meaning that coordination and collaboration with the whole channel partners include suppliers, third party service providers, consumers. SCM Activities include planning and management of all sourcing and procurement, conversion and overall logistics activities (CSCMP, 2013). Current research tends to combine other concepts into SCM, one of the main ones is sustainability.

Sustainability is a multidimensional and complex issue that makes environmental, economic, and social the basis of efficiency. This is intended to solve problems such as climate change, biodiversity loss, decreasing material availability (Vinodh & Girubha, 2012). The concept of sustainability becomes an important concept in governance and policy including the palm oil industry.

Meanwhile sustainable supply chain management (SSCM) is a method that tries to integrate environmental, social and economic factors into the company's overall supply chain, developing rapidly (Koberg & Longoni, 2019). SSCM research in the palm oil industry has also been carried out, including by Munasinghe et al. (2018) by identifying critical sustainability issues in the palm oil industry supply chain using life cycle assessment (LCA) and Lyons-white and Knight (2018) by investigating the structure of the palm oil industry supply chain on the effectiveness of implementing a no-deforestation commitment.

Supply Chain Risk Management

Risk management is executed based on company’s own policies and best practices, it is seen as a systematic process in industrial establishment (Miftaur, Khan, Sujan, & Ahm, 2018)

SCRM tries to implement risk management into a supply chain. According to Tang and Musa (2011) supply chain risk definition must refer to (i) events with small probability but if they occur abruptly, (ii) this event has a significant negative impact on the system, thus the definition of SCRM refers to S.Tang (2006) namely supply chain risk management through coordination or collaboration between supply chain partners to ensure profits and sustainability. The main stages in SCRM generally consist of risk identification, risk assessment, risk analysis, risk treatment and monitoring (Giannakis & Papadopoulos, 2016). However Kumar, Himes, and Kritzer (2014) identified four models in the SCRM.

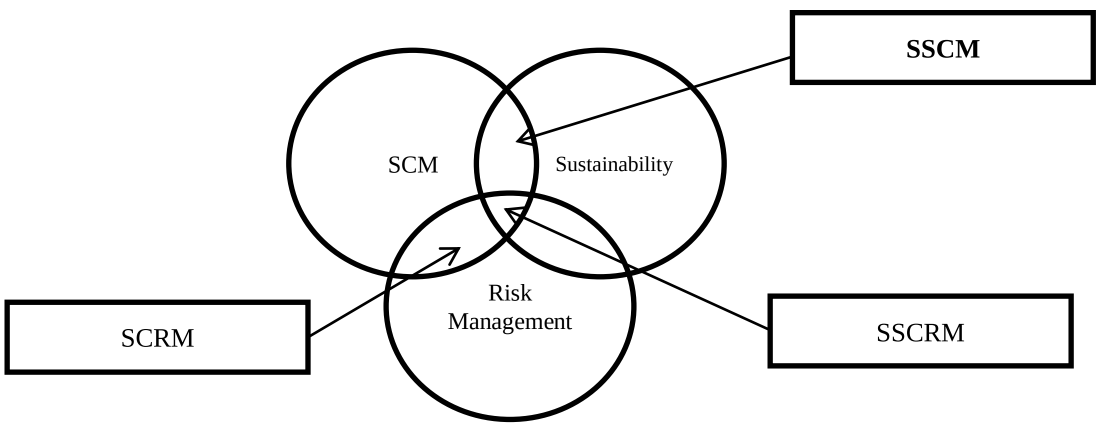


**Fig 1.** Supply chain risk management scientific intersection

The first SCRM model that refers to Zsidisin and Ellram (2003) there are ten stages: Identify material or service, appoint manager to own the process, initiate risk assessment score card assessment, review criteria for each risk factor, collect data for each risk factor, assign risk scores, conduct impact analysis,

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document analysis and actions, monitoring, determine to cease assessment. The second model that refers to Pickett (2006) has six stages: Identify all critical suppliers of materials or services, estimate the probability and frequency of it business failure or supply disruption, estimate the potential impact of supply disruption, evaluate current business relationships with each critical supplier, identify and implement appraisal risk mitigation strategies, identify and implement the appraisal metrics to evaluate the effectiveness of selected supply risk mitigation strategies. The third model that refers to Manuj and Mentzer (2008) has five stages: risk

identification, risk assessment and evaluation, selection of appraisal risk management, implementation of supply chain risk management strategies, mitigation of supply chain risk. The fourth model that refers to Ericsson's Model (Norrman, 2004) has four stages: risk identification, risk assessment, risk treatment-contingency planning-incident handling, risk monitoring.

Sustainable Supply Chain Risk Management

The concept of sustainable supply chain risk management (SSCRM) in this study is a combination of the concepts of supply chain management (SCM), risk management (RM) and sustainability as shown in Fig 1. Rostamzadeh, Keshavarz, and Govindan (2018) have conducted SSCRM research with integrated fuzzy multi-criteria-decision-making (MCDM) method on the basis of preference by similarity to ideal solution (TOPSIS) and criteria of importance through inter-criteria correlation (CRITIC).

Research on SSCRM has also been carried out by Valinejad and Rahmani (2018) who tried to offer a framework for managing the sustainability risks in the supply chain of telecommunications companies. In this research, sustainability risks in the supply chain are classified into five dimensions of sustainability including technical sustainability, economic sustainability, social sustainability, environmental sustainability, and institutional sustainability. In this case the risk management approach is used as a way to identify supply chain risks, then the FMEA approach is used in assessing the identified risks. While Giannakis and Papadopoulos (2016) conducted a study of SSCRM beginning with a literature review and personal interview that found 30 risks across the main pillars of sustainability (environmental, social and economic). Then the FMEA method is used as a tool to create a probability rating for occurrence, severity and detectability for each risk. FMEA and pareto analysis are then used in calculating risk priority number (RPN) and prioritizing risks. Afterwards, correlation analysis is used for each prioritized risk, and finally case studies are used in finding strategies to mitigate each risk event.

**Method**

In general, this research was developed as follows: First, sustainability-related supply chain risk for the palm oil industry in Indonesia is identified through the ISPO and RSPO principles and criteria. Second, every identified sustainability-related supply chain risk is requested by experts to provide an assessment of occurrence (O), severity (S), detectability, and weight of importance (W) with the fuzzy FMEA method of linguistic approach (Zadeh, 1975).Third, the Risk Priority Number with the fuzzy linguistic (RPND) approach is calculated as the basis for prioritizing each sustainability-related supply chain risk and ranking. Fourth, interviews were conducted with experts to develop risk response and risk treatment strategies for each sustainability-related supply chain risk. Finally, a sustainable supply chain risk management framework for the palm oil industry in Indonesia was developed.

**Identify Sustainability-related Supply Chain Risk**

Content analysis was carried out on ISPO principle documents and criteria issued by Indonesia government (Indonesia Ministry of Agriculture (2015) and RSPO principle documents and criteria (RSPO 2013).This process resulted in 45 sustainability-related supply chain risks for the palm oil industry in Indonesia which are divided into three sustainability categories, namely 21 environmental categories, 12 social categories, and 12 financial or economic categories, as shown in Table 1.

**Assessment of Experts on Identified Sustainability-related Supply Chain Risk**

Five experts in the palm oil industry are each given a weight according to their level of expertise, where the Mill Manager (expert 1; 0.25), Plantation Manager (expert 2; 0.25), Assistant Mill Manager (expert 3; 0.15), Assistant Plantation Manager (expert 4, 0.15), and Head of Health Safety Environmental Manager (expert 5; 0.20), with a total expertise weight of the five experts being 1. The five experts were

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asked for their evaluation of each identified sustainability-related supply of risk according to the fuzzy linguistics approach for occurrence, severity, and detection according to Table 2.

**Table 2.** O, S, D fuzzy linguistics and corresponding fuzzy number

| **Risk Factor** | **Fuzzy linguistic terms** | | | | |
|---|---|---|---|---|---|
| **Occurrence** | VL (very low) | L (low) | M (medium) | H (high) | VH (very high) |
| **Severity** | N (none) | Sl (slight) | Md (moderate) | HS (high severity) | VHS (very high severity) |
| **Detection** | EL (extremely likely chances of detection | HC (high chances of detection) | MC (moderate chances of detection) | LC (low chances of detection) | EU (extremely likely chances of un-detection) |
| **Corresponding fuzzy numbers** | 0,1,3 | 1,3,5 | 3,5,7 | 5,7,9 | 7,9,10 |

The assessment of the five experts can be seen in Table 3. Then the five experts were also asked to assess the importance of each identified sustainability-related supply chain risk with the fuzzy linguistics approach as shown in Table 4, while the results of the assessment appear in Table 5.

Expert opinions in Table 3 and Table 5 are then calculated with Eq. (1) to Eq. (9).The weight of each expert is calculated using the Eq (1) because each expert has a different effect on the end result (Lin, Wang, Lin, & Liu, 2014).

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**Table 1.** Sustainability-related supply chain risk for palm oil industry in Indonesia

| Risk Code | Risk Category | Risk |
|---|---|---|
| E1 | Environmental | Low fertility soil |
| E2 | | Soil degradation |
| E3 | | Flood |
| E4 | | High BOD (biological oxygen demand) |
| E5 | | Mill water use per ton of FFB is high |
| E6 | | High chemical use |
| E7 | | Improper disposal waste |
| E8 | | POME is not well managed |
| E9 | | Lack of conservation of habitat for endangered species around the company |
| E10 | | Operations in the High Conservation Value (HCV) area |
| E11 | | Human-wildlife conflict occurred |
| E12 | | Greenhouse gases pollution |
| E13 | | High fuel usage |
| E14 | | Fire in the estate area |
| E15 | | Burning in land clearing |
| E16 | | High waste produced |
| E17 | | Contamination of waste with raw water |
| E18 | | B3 waste management is close to the activities of the society |
| E19 | | Road construction is not in accordance with SOP |
| E20 | | Waste leakage |
| E21 | | Poor waste water treatment plant management |
| S1 | Social | Land use dispute |
| S2 | | Employees do not use safety equipment |
| S3 | | High work accident |
| S4 | | Lack of employee training |
| S5 | | Unhealthy working condition |
| S6 | | Inadequate employee housing facilities |
| S7 | | Inadequate education and health facilities |
| S8 | | The employee is not covered by health insurance |
| S9 | | The surrounding community lacks employment opportunities |
| S10 | | Employing underage children |
| S11 | | Looting of FFB (fresh fruit bunch) |
| S12 | | Lack of socialization of company policies to employees and surrounding communities |
| F1 | Financial/Economic | Bribery |
| F2 | | Low OER (oil extraction rate) |
| F3 | | High cost of production |
| F4 | | Low CPO prices |
| F5 | | Un-fulfill mill processing capacity |
| F6 | | Tax fraud |
| F7 | | Transport for FFB is lacking |
| F8 | | Unplanned replanting |
| F9 | | Limited information and access to CPO marketing |
| F10 | | Unfair FFB Price |
| F11 | | The CPO stock did not match the results of the audit |
| F12 | | Unplanned reclamation cost |

**Table 4.** Fuzzy linguistic scale for all of risks

| Fuzzy linguistics terms | Unimportant (U) | Less Important (L) | Medium Important (M) | Important (I) | Very Important (VI) |
|---|---|---|---|---|---|
| Corresponding fuzzy number | 0, 0, 0.15 | 0.1, 0.25, 0.4 | 0.35, 0.5, 0.65 | 0.6, 0.75, 0.9 | 0.85, 1, 1 |

$$W_{Ek} = \frac{E_k}{\sum_{k=1}^{n} E_k}, \; k = 1,2,3,\ldots,n \qquad (1)$$

Where E and kth are a team of experts and the level of expertise.

Occurrence, severity, and detection are sequentially symbolized $O_{ij}^{n}$, $S_{ij}^{n}$, $D_{ij}^{n}$ (Eqs.2-4) are evaluated by n experts for interface i and risk j where $O_{ij}^{n}$, $S_{ij}^{n}$, $D_{ij}^{n}$ $\epsilon$ T is a membership function for triangular fuzzy numbers according to Table 2. While the importance weight symbolized $W_{ij}^{n}$ (Eq.5) is also evaluated by n experts for interface i and risk j, $W_{ij}^{n}$ $\epsilon$ S TFN membership function according to Table 4

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**Table 3.**Evaluation of O, S, D by all experts using fuzzy linguistics terms

| Risk Code | O | | | | | S | | | | | D | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ex1 (0.25) | Ex2 (0.25) | Ex3 (0.15) | Ex4 (0.15) | Ex5 (0.20) | Ex1 (0.25) | Ex2 (0.25) | Ex3 (0.15) | Ex4 (0.15) | Ex5 (0.20) | Ex1 (0.25) | Ex2 (0.25) | Ex3 (0.15) | Ex4 (0.15) | Ex5 (0.20) |
| **E1** | VL | L | L | VL | M | Md | Md | Sl | HS | Md | MC | LC | MC | LC | EU |
| **E2** | VL | VL | L | VL | L | Sl | Md | Sl | Sl | Md | LC | LC | MC | LC | EU |
| **E3** | VL | VL | VL | VL | L | HS | VHS | HS | HS | HS | EU | EU | LC | EU | EU |
| **E4** | L | M | M | H | M | Sl | Sl | Sl | Sl | N | MC | MC | HC | HC | MC |
| **E5** | VH | H | M | M | L | Md | Sl | Sl | Sl | Sl | LC | EU | EU | LC | EU |
| **E6** | H | M | H | L | M | Md | Md | Md | Sl | Md | HC | EL | HC | HC | HC |
| **E7** | VL | VL | VL | L | VL | Md | HS | Sl | Md | Md | EL | EL | EL | EL | EL |
| **E8** | H | M | L | VL | M | VHS | HS | Md | HS | Md | EL | HC | HC | HC | EL |
| **E9** | VL | VL | L | VL | L | Sl | Md | Md | Sl | Md | EL | EL | HC | EL | HC |
| **E10** | M | L | VL | L | VL | Md | Md | Md | HS | HS | LC | EU | LC | EU | LC |
| **E11** | H | M | L | VL | VL | HS | Md | HS | Md | Md | EL | HC | EL | HC | EL |
| **E12** | M | L | H | M | M | Sl | Sl | Md | Md | Sl | MC | LC | LC | MC | LC |
| **E13** | VH | H | M | M | H | Md | Md | Sl | HS | Md | EL | HC | HC | EL | HC |
| **E14** | VL | VL | L | VL | L | VHS | HS | HS | VHS | HS | EL | HC | HC | HC | HC |
| **E15** | H | M | L | L | M | HS | HS | HS | VHS | HS | HC | HC | EL | HC | HC |
| **E16** | VH | H | H | M | H | Md | Md | Md | HS | Md | HC | MC | HC | HC | MC |
| **E17** | VL | VL | L | VL | VL | HS | HS | HS | Md | HS | MC | LC | EU | LC | EU |
| **E18** | VL | VL | L | L | VL | Md | Sl | Md | Md | Sl | EL | EL | EL | HC | HC |
| **E19** | M | L | VL | M | L | Sl | Md | Sl | Sl | Md` | MC | HC | HC | MC | HC |
| **E20** | VL | VL | VL | L | VL | HS | VHS | Md | HS | Md | HC | HC | MC | HC | HC |
| **E21** | L | VL | VL | VL | VL | Md | HS | HS | Md | HS | EL | HC | EL | HC | EL |
| **S1** | M | M | L | L | VL | VHS | HS | VHS | HS | Md | EL | HC | EL | HC | EL |
| **S2** | VH | H | M | M | H | Md | HS | Sl | Md | HS | EL | HC | EL | EL | HC |
| **S3** | L | M | VL | M | L | VHS | HS | HS | Md | HS | HC | HC | HC | MC | HC |
| **S4** | VH | VH | H | VH | M | Md | Sl | Md | Sl | Md | EL | HC | EL | HC | EL |
| **S5** | H | VH | M | H | M | HS | Md | Md | HS | Sl | MC | HC | HC | HC | EL |
| **S6** | M | H | H | VH | H | Md | HS | Md | Md | Md | EL | EL | HC | EL | EL |
| **S7** | M | L | M | M | L | Md | Sl | Sl | Md | Sl | HC | EL | EL | HC | EL |
| **S8** | L | VL | M | L | VL | HS | Md | HS | Md | HS | HC | HC | EL | HC | EL |
| **S9** | L | VL | L | VL | M | HS | HS | Md | HS | Md | MC | HC | EL | EL | HC |
| **S10** | VL | VL | L | VL | L | VHS | HS | HS | HS | HS | HC | EL | HC | EL | HC |
| **S11** | M | L | M | L | M | HS | Md | HS | Md | HS | EU | LC | LC | MC | EU |
| **S12** | H | M | H | H | H | Md | Md | Md | Md | HS | HC | MC | HC | HC | HC |
| **F1** | VL | VL | VL | L | VL | Md | Sl | Sl | Md | Md | EU | LC | LC | EU | EU |
| **F2** | VH | H | VH | M | H | HS | HS | HS | Md | HS | MC | HC | HC | MC | HC |
| **F3** | H | M | M | VH | H | HS | Md | HS | Md | Md | MC | HC | HC | EL | HC |
| **F4** | H | M | VH | M | H | HS | Md | Md | HS | Md | MC | MC | HC | MC | HC |
| **F5** | H | M | H | M | H | Md | Md | HS | Md | Md | MC | LC | MC | MC | MC |
| **F6** | L | L | VL | VL | VL | HS | HS | Md | HS | Md | EL | HC | MC | HC | MC |
| **F7** | M | L | L | M | M | Md | Sl | Sl | Sl | Md | EL | EL | HC | HC | EL |
| **F8** | VL | L | VL | VL | VL | HS | HS | Md | HS | Md | HC | HC | EL | HC | EL |
| **F9** | L | VL | VL | L | VL | Md | HS | Md | HS | Md | HC | EL | EL | HC | EL |
| **F10** | M | L | L | M | M | Md | Sl | Md | HS | Md | EL | EL | HC | HC | EL |
| **F11** | H | H | VH | H | VH | Md | Sl | Md | Md | Sl | HC | EL | HC | HC | HC |
| **F12** | VL | VL | L | L | VL | Sl | Md | Md | Sl | Md | EL | HC | HC | EL | HC |

**Table 5.**Weight of Importance of all **s**ustainability-related supply chain risk for palm oil industry in Indonesia by experts

| Risk Code | W | | | | |
|---|---|---|---|---|---|
| | Ex1 | Ex2 | Ex3 | Ex4 | Ex5 |
| **E1** | M | I | M | M | L |
| **E2** | L | U | L | U | L |
| **E3** | L | L | U | M | L |
| **E4** | U | L | U | M | L |
| **E5** | U | U | U | L | U |
| **E6** | I | M | L | M | I |
| **E7** | I | L | I | L | L |
| **E8** | M | I | M | I | M |
| **E9** | I | I | M | L | I |
| **E10** | I | M | L | I | I |

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| | | | | | |
|---|---|---|---|---|---|
| **E11** | I | M | M | M | L |
| **E12** | I | I | I | M | M |
| **E13** | M | M | L | M | M |
| **E14** | VI | I | VI | I | M |
| **E15** | M | I | M | L | M |
| **E16** | U | L | L | U | L |
| **E17** | L | M | L | M | M |
| **E18** | U | L | U | L | L |
| **E19** | U | U | U | U | L |
| **E20** | I | I | I | M | I |
| **E21** | M | M | M | L | I |
| **S1** | I | I | M | I | M |
| **S2** | M | L | L | M | L |
| **S3** | I | VI | I | M | M |
| **S4** | L | L | M | L | M |
| **S5** | M | M | I | I | M |
| **S6** | I | I | I | VI | M |
| **S7** | M | L | M | L | L |
| **S8** | M | I | M | M | I |
| **S9** | I | VI | I | VI | I |
| **S10** | L | L | U | M | L |
| **S11** | I | VI | M | I | I |
| **S12** | L | L | U | M | L |
| **F1** | M | L | L | L | M |
| **F2** | I | VI | I | VI | VI |
| **F3** | VI | VI | I | VI | VI |
| **F4** | I | I | M | I | M |
| **F5** | I | M | M | M | I |
| **F6** | U | L | L | U | L |
| **F7** | I | M | M | I | M |
| **F8** | U | L | L | L | U |
| **F9** | U | L | U | L | L |
| **F10** | L | L | L | M | L |
| **F11** | U | L | L | U | L |
| **F12** | L | U | U | L | U |

$$O_{ij}^{n} = (OL_{ij}^{n}, OM_{ij}^{n}, OU_{ij}^{n}), O_{ij}^{n} \in T, \text{where } 0 \leq OL_{ij}^{n} \leq OM_{ij}^{n} \leq OU_{ij}^{n} \leq 10. \quad (2)$$
$$S_{ij}^{n} = (SL_{ij}^{n}, SM_{ij}^{n}, SU_{ij}^{n}), S_{ij}^{n} \in T, \text{where } 0 \leq SL_{ij}^{n} \leq SM_{ij}^{n} \leq SU_{ij}^{n} \leq 10. \quad (3)$$
$$D_{ij}^{n} = (DL_{ij}^{n}, DM_{ij}^{n}, DU_{ij}^{n}), D_{ij}^{n} \in T, \text{where } 0 \leq DL_{ij}^{n} \leq DM_{ij}^{n} \leq DU_{ij}^{n} \leq 10. \quad (4)$$
$$W_{ij}^{n} = (WL_{ij}^{n}, WM_{ij}^{n}, WU_{ij}^{n}), W_{ij}^{n} \in S, \text{where } 0 \leq WL_{ij}^{n} \leq WM_{ij}^{n} \leq WU_{ij}^{n} \leq 10. \quad (5)$$
$$O_{ij} = O_{ij}^{1} \text{ x } W_{E1} + O_{ij}^{2} \text{ x } W_{E2} + ... + O_{ij}^{n} \text{ x } W_{En} \quad (6)$$
$$S_{ij} = S_{ij}^{1} \text{ x } W_{E1} + S_{ij}^{2} \text{ x } W_{E2} + ... + S_{ij}^{n} \text{ x } W_{En} \quad (7)$$
$$D_{ij} = D_{ij}^{1} \text{ x } W_{E1} + D_{ij}^{2} \text{ x } W_{E2} + ... + D_{ij}^{n} \text{ x } W_{En} \quad (8)$$
$$W_{ij} = W_{ij}^{1} \text{ x } W_{E1} + W_{ij}^{2} \text{ x } W_{E2} + ... + W_{ij}^{n} \text{ x } W_{En} \quad (9)$$

Probability of occurrence (O), severity (S), Detection based on fuzzy number, and fuzzy weight of each sustainability-related supply chain risk for palm oil industry in Indonesia by all experts (W) are aggregated by using Eq. (6)-(9) (Lin, Liu, Liu, & Wang, 2013). Where $O_{ij}$, $S_{ij}$, $D_{ij}$ are values of occurrence, severity, and detection from expert judgement for interface i and risk j. While $W_{ij}$ is importance for each sustainability-related supply chain risk evaluated by experts for interface i and risk j. Aggregated calculation results from Eq. 1 to Eq.2 are shown in Table 6.

**Table 6.** Aggregated fuzzy information for all **s**ustainability-related supply chain risk for palm oil industry in Indonesia

| | | **O** | | | **S** | | | **D** | | | **W** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | OL*j* | Om*j* | Ou*j* | SL*j* | SM*j* | Su*j* | DL*j* | DMj | Du*j* | WLj | WMj | Wuj |

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| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **E1** | 1 | 2.6 | 4.6 | 2.25 | 5 | 7 | 4.60 | 6.60 | 8.40 | 0.36 | 0.51 | 0.66 |
| **E2** | 0.35 | 1.7 | 3.7 | 1.65 | 3.9 | 5.9 | 5.10 | 7.10 | 8.90 | 0.06 | 0.15 | 0.30 |
| **E3** | 0.2 | 1.4 | 3.4 | 4.25 | 7.5 | 9.25 | 6.70 | 8.70 | 9.85 | 0.12 | 0.25 | 0.40 |
| **E4** | 2.8 | 4.8 | 6.8 | 0.55 | 2.6 | 4.6 | 2.40 | 4.40 | 6.40 | 0.10 | 0.19 | 0.34 |
| **E5** | 4.1 | 6.1 | 7.85 | 0.75 | 3.5 | 5.5 | 6.20 | 8.20 | 9.60 | 0.02 | 0.04 | 0.19 |
| **E6** | 3.5 | 5.5 | 7.5 | 1.95 | 4.7 | 6.7 | 0.75 | 2.50 | 4.50 | 0.43 | 0.58 | 0.73 |
| **E7** | 0.15 | 1.3 | 3.3 | 2.45 | 5.2 | 7.2 | 0.00 | 1.00 | 3.00 | 0.30 | 0.45 | 0.60 |
| **E8** | 2.75 | 4.6 | 6.6 | 3.05 | 6.8 | 8.55 | 0.55 | 2.10 | 4.10 | 0.45 | 0.60 | 0.75 |
| **E9** | 0.35 | 1.7 | 3.7 | 1.95 | 4.2 | 6.2 | 0.35 | 1.70 | 3.70 | 0.49 | 0.64 | 0.79 |
| **E10** | 1.15 | 2.8 | 4.8 | 2.95 | 5.7 | 7.7 | 5.80 | 7.80 | 9.40 | 0.46 | 0.61 | 0.76 |
| **E11** | 2.15 | 3.8 | 5.8 | 2.55 | 5.8 | 7.8 | 0.40 | 1.80 | 3.80 | 0.36 | 0.51 | 0.66 |
| **E12** | 2.8 | 4.8 | 6.8 | 1.35 | 3.6 | 5.6 | 4.20 | 6.20 | 8.20 | 0.51 | 0.66 | 0.81 |
| **E13** | 4.9 | 6.9 | 8.65 | 2.25 | 5 | 7 | 0.60 | 2.20 | 4.20 | 0.31 | 0.46 | 0.61 |
| **E14** | 0.35 | 1.7 | 3.7 | 4.05 | 7.8 | 9.4 | 0.75 | 2.50 | 4.50 | 0.65 | 0.80 | 0.89 |
| **E15** | 2.9 | 4.9 | 6.9 | 4.05 | 7.3 | 9.15 | 0.85 | 2.70 | 4.70 | 0.38 | 0.53 | 0.68 |
| **E16** | 5.2 | 7.2 | 8.95 | 2.55 | 5.3 | 7.3 | 1.90 | 3.90 | 5.90 | 0.06 | 0.15 | 0.30 |
| **E17** | 0.15 | 1.3 | 3.3 | 3.45 | 6.7 | 8.7 | 5.20 | 7.20 | 8.85 | 0.25 | 0.40 | 0.55 |
| **E18** | 0.3 | 1.6 | 3.6 | 1.35 | 4.1 | 6.1 | 0.35 | 1.70 | 3.70 | 0.06 | 0.15 | 0.30 |
| **E19** | 1.65 | 3.5 | 5.5 | 1.65 | 3.9 | 5.9 | 1.80 | 3.80 | 5.80 | 0.02 | 0.05 | 0.20 |
| **E20** | 0.15 | 1.3 | 3.3 | 3.55 | 6.8 | 8.55 | 1.30 | 3.30 | 5.30 | 0.56 | 0.71 | 0.86 |
| **E21** | 0.25 | 1.5 | 3.5 | 3.45 | 6.2 | 8.2 | 0.40 | 1.80 | 3.80 | 0.36 | 0.51 | 0.66 |
| **S1** | 1.8 | 3.6 | 5.6 | 3.65 | 7.4 | 9 | 0.40 | 1.80 | 3.80 | 0.51 | 0.66 | 0.81 |
| **S2** | 4.9 | 6.9 | 8.65 | 2.85 | 5.6 | 7.6 | 0.45 | 1.90 | 3.90 | 0.20 | 0.35 | 0.50 |
| **S3** | 1.65 | 3.5 | 5.5 | 3.45 | 7.2 | 8.95 | 1.30 | 3.30 | 5.30 | 0.58 | 0.73 | 0.84 |
| **S4** | 5.9 | 7.9 | 9.25 | 1.45 | 4.2 | 6.2 | 0.40 | 1.80 | 3.80 | 0.19 | 0.34 | 0.49 |
| **S5** | 4.8 | 6.8 | 8.55 | 2.15 | 5.4 | 7.4 | 1.30 | 3.10 | 5.10 | 0.43 | 0.58 | 0.73 |
| **S6** | 4.8 | 6.8 | 8.65 | 2.75 | 5.5 | 7.5 | 0.15 | 1.30 | 3.30 | 0.59 | 0.74 | 0.87 |
| **S7** | 2.1 | 4.1 | 6.1 | 1.05 | 3.8 | 5.8 | 0.40 | 1.80 | 3.80 | 0.20 | 0.35 | 0.50 |
| **S8** | 0.85 | 2.4 | 4.4 | 2.95 | 6.2 | 8.2 | 0.65 | 2.30 | 4.30 | 0.46 | 0.61 | 0.76 |
| **S9** | 1 | 2.6 | 4.6 | 3.05 | 6.3 | 8.3 | 1.20 | 2.90 | 4.90 | 0.70 | 0.85 | 0.94 |
| **S10** | 0.35 | 1.7 | 3.7 | 3.75 | 7.5 | 9.25 | 0.60 | 2.20 | 4.20 | 0.12 | 0.25 | 0.40 |
| **S11** | 2.2 | 4.2 | 6.2 | 2.95 | 6.2 | 8.2 | 5.60 | 7.60 | 9.15 | 0.63 | 0.78 | 0.89 |
| **S12** | 4.5 | 6.5 | 8.5 | 2.65 | 5.4 | 7.4 | 1.50 | 3.50 | 5.50 | 0.12 | 0.25 | 0.40 |
| **F1** | 0.15 | 1.3 | 3.3 | 1.45 | 4.2 | 6.2 | 6.20 | 8.20 | 9.60 | 0.21 | 0.36 | 0.51 |
| **F2** | 5.5 | 7.5 | 9.1 | 3.45 | 6.7 | 8.7 | 1.80 | 3.80 | 5.80 | 0.75 | 0.90 | 0.96 |
| **F3** | 4.5 | 6.5 | 8.35 | 2.55 | 5.8 | 7.8 | 1.35 | 3.20 | 5.20 | 0.81 | 0.96 | 0.99 |
| **F4** | 4.5 | 6.5 | 8.35 | 2.55 | 5.8 | 7.8 | 2.30 | 4.30 | 6.30 | 0.51 | 0.66 | 0.81 |
| **F5** | 4.2 | 6.2 | 8.2 | 2.55 | 5.3 | 7.3 | 3.50 | 5.50 | 7.50 | 0.46 | 0.61 | 0.76 |
| **F6** | 0.5 | 2 | 4 | 3.05 | 6.3 | 8.3 | 1.45 | 3.20 | 5.20 | 0.06 | 0.15 | 0.30 |
| **F7** | 2.2 | 4.2 | 6.2 | 1.15 | 3.9 | 5.9 | 0.30 | 1.60 | 3.60 | 0.45 | 0.60 | 0.75 |
| **F8** | 0.25 | 1.5 | 3.5 | 3.05 | 6.3 | 8.3 | 0.65 | 2.30 | 4.30 | 0.06 | 0.14 | 0.29 |
| **F9** | 0.4 | 1.8 | 3.8 | 3.05 | 5.8 | 7.8 | 0.40 | 1.80 | 3.80 | 0.06 | 0.15 | 0.30 |
| **F10** | 2.2 | 4.2 | 6.2 | 2.05 | 4.8 | 6.8 | 0.30 | 1.60 | 3.60 | 0.14 | 0.29 | 0.44 |
| **F11** | 5.7 | 7.7 | 9.35 | 1.35 | 4.1 | 6.1 | 0.75 | 2.50 | 4.50 | 0.06 | 0.15 | 0.30 |
| **F12** | 0.3 | 1.6 | 3.6 | 1.95 | 4.2 | 6.2 | 0.60 | 2.20 | 4.20 | 0.04 | 0.10 | 0.25 |

## Calculate Risk Priority Number by Using Fuzzy Linguistic

Failure mode and effects analysis (FMEA) was first offered by NASA in 1963 as obvious reliability requirements. Since then the FMEA method has developed very rapidly in various industries. In the initial FMEA the measurement of risk priority number (RPN) is multiplication of the probability of occurrence (O), severity (S), and detection (D) (Bahrami, Hadizadeh, & Sajjadi, 2012). RPN with higher values are assumed to be more important and are given higher priority than that with lower values (Mariajayaprakash, Senthilvelan, & Vivekananthan, 2013)Meanwhile for fuzzy FMEA in this study the measurement of risk priority number by fuzzy number (RPND) is by Eq. (10)

RPND = DOk x DSk x DDk x DWk (10)

Where ,

$$\mathrm{DO}k = \frac{(OU_k - OL_k) + (OM_k - OL_k)}{3} + OL_k \quad \forall k \tag{11}$$

$$\mathrm{DS}k = \frac{(SU_k - SL_k) + (SM_k - SL_k)}{3} + SL_k \quad \forall k \tag{12}$$

$$DDk = \frac{(DU_k - DL_k) + (DM_k - DL_k)}{3} + DL_k \quad \forall k \qquad (13)$$

$$DWk = \frac{(WU_k - WL_k) + (WM_k - WL_k)}{3} + WL_k \quad \forall k \qquad (14)$$

The results of the $RPN_D$ calculation are used as the basis for ranking each sustainability-related supply chain risk. The $RPN_D$ as well as the ranking are shown in Table 7.

**Develop Risk Response and Risk Treatment**

This stage includes interviews with one of the experts in the palm oil industry. A mill manager is asked a question about the company's possible response to the identified sustainability-related supply chain risk. Each response is categorized into avoidance, prevention, mitigation, cooperation, insurance, and retention.

3.5 Develop Sustainable Supply Chain Risk Management Framework

The final stage of this research is to develop a sustainable supply chain risk management framework that illustrates how sustainability-related risk in the palm oil industry is identified until handled. The framework appears in Fig. 2

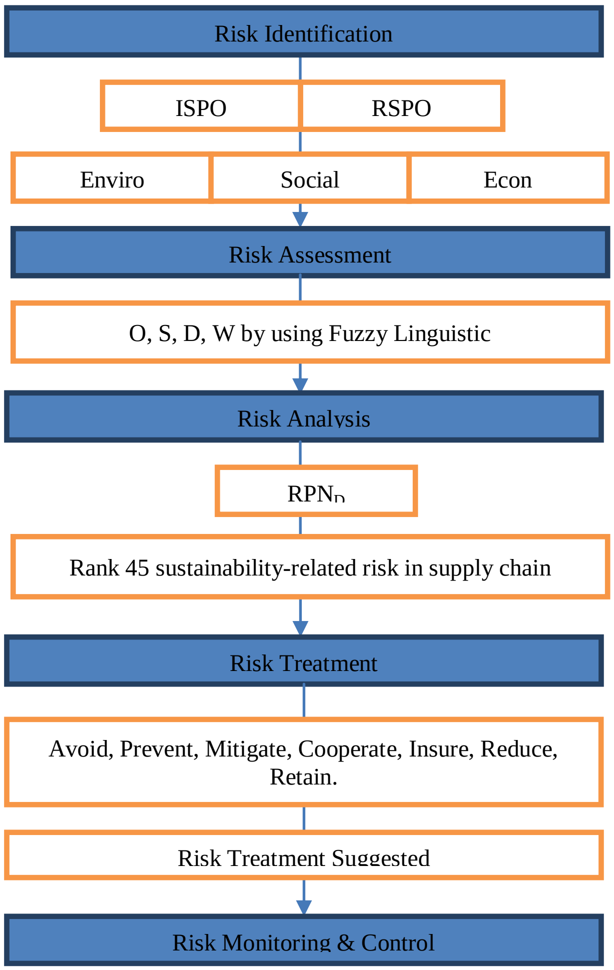


**Fig 2.**SSCRM framework for palm oil industry in Indonesia

**Table 7.** $RPN_D$ values and risk treatment for all **s**ustainability-related supply chain risk for palm oil industry in Indonesia

| Risk Code | Sustainability-related supply chain risk | $RPN_D$ | Rank | Risk Response | Risk treatment suggested |
|---|---|---|---|---|---|
| **F2** | Low OER (oil extraction rate) | 153.03 | 1 | – Avoid<br>– Prevent | – Reduce the percentage of unripe FFB (Fresh fruit bunch) receipts<br>– Extend sterilizing period at the sterilizer station |

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| | | | | | |
|---|---|---|---|---|---|
| | | | | – Reduce<br>– Mitigate | – Reduce oil losses at the press station<br>– Gain oil in cooling pond |
| **S11** | Looting of FFB (fresh fruit bunch) | 137.98 | 2 | – Prevent<br>– Mitigate<br>– Cooperate | – Identification of looting-prone areas<br>– Involve the local community in protecting the plantation area<br>– Collaborate with nearby companies to only accept FFB from a clear origin |
| **F5** | Un-fulfill mill processing capacity | 105.48 | 3 | – Prevent<br>– Avoid<br>– Reduce | – Perform preventive maintenance, especially for critical machines<br>– Provide sufficient spare parts for critical machinery<br>– Schedule boiler station operators and engine rooms to enter work early to prepare for operation |
| **F3** | High cost of production | 103.82 | 4 | – Avoid<br>– Prevent | – Set the schedule for only one shift and leave employees free if a severe breakdown occurs<br>– Limit the number of mill hours of operation if the FFB information comes in a little |
| **F4** | Low CPO prices | 98.92 | 5 | – Retain | – Hold production at low levels while waiting for normal prices |
| **E10** | Operations in the High Conservation Value (HCV) area | 74.64 | 6 | – Avoid | – Map concessions of land held into HCV areas and non-HCVs prior to expansion |
| **E12** | Greenhouse gases pollution | 69.33 | 7 | – Avoid<br>– Prevent<br>– Mitigate | – Reduce the use of diesel fuel in the mill<br>– Monitor CO2 Footprint along the supply chain<br>– Keep the using of chemicals to a minimum |
| **S5** | Unhealthy working condition | 60.95 | 8 | – Prevent<br>– Insure<br>– Reduce | – Provision of safety training programs for employees<br>– Providing full medical insurance for employees<br>– Safety instruction and contingency plan |
| **S3** | High work accident | 54.53 | 9 | – Prevent<br>– Insure<br>– Reduce | – Use of 100% safety equipment both in estate and mill<br>– Providing full medical insurance for employees<br>– Ensure manual procedures for each equipment and machine are applied |
| **E15** | Burning in land clearing | 48.34 | 10 | – Avoid<br>– Prevent | – Only non-burning land clearing, sanctions or layoffs of employees who do the burning are allowed<br>– Have an official land clearing manual procedure |
| **E1** | Low fertility soil | 43.47 | 11 | – Avoid<br>– Prevent | – Not excessive using of fertilizer and chemical<br>– Prioritize the implementation of land applications and organic fertilizers |
| **S6** | Inadequate employee housing facilities | 40.96 | 12 | – Prevent | – Always budgeted in capital expenditure for addition and improvement of employee housing |
| **S9** | The surrounding community lacks employment opportunities | 40.04 | 13 | – Prevent | – Always provide adequate portions for local people every time they recruit |
| **E8** | POME is not well managed | 38.50 | 14 | – Mitigate<br>– Prevent | – Provide operators with sufficient each shift to manage disposal and effluent<br>– Create a program for making organic fertilizer from POME, chopped empty bunch, and solid waste. |
| **E6** | High chemical use | 36.36 | 15 | – Avoid<br>– Prevent | – Using combination of chemical and organic fertilizer<br>– Orderly measurements and timetable fertilizer |
| **E13** | High fuel usage | 34.94 | 16 | – Prevent | – Keep the boiler pressure stable, so you don't need to use the generator frequently |
| **S1** | Land use dispute | 32.47 | 17 | – Avoid<br>– Cooperate<br>– Reduce | – Map the concession of land owned if there are parts that overlap with community land<br>– Make two-way communication with communities where the land is overlapping, offer a plasma program<br>– Hire influential local residents as part of public relations and community empowerment |
| **S12** | Lack of socialization of company policies to employees and surrounding communities | 30.17 | 18 | – Prevent<br>– Mitigate | – Create community empowerment programs according to local needs<br>– Hire a public relations and community empowerment division of professionals and local residents |
| **E17** | Contamination of waste with raw water | 28.19 | 19 | – Avoid | – Separate with sufficient distance between the source and the raw water channel with the waste effluent pond |
| **E14** | Fire in the estate area | 27.36 | 20 | – Prevent<br>– Mitigate | – Monitor hotspots during the dry season using satellite imagery<br>– Create clear action plan for each estate employee when a fire breaks out |
| **S2** | Employees do not use safety equipment | 26.59 | 21 | – Prevent<br>– Reduce | – Providing training on safety for employees<br>– Bosses always remind when employees do not use safety equipment |
| **E3** | Flood | 25.29 | 22 | – Mitigate<br>– Insure | – Contingency plan for supply chain resilience<br>– Insure against disaster including flood |
| **E16** | High waste produced | 23.83 | 24 | – Reduce<br>– Mitigate | – Reduce the percentage of waste in FFB received<br>– Reduce oil losses at the clarification station |
| **E20** | Waste leakage | 23.45 | 24 | – Avoid<br>– Prevent<br>– Mitigate | – Keep waste effluent pond strong enough<br>– Always control the volume of waste at the pond or at disposal<br>– Make sure the leaked waste does not spread widely by covering the leak point |
| **S8** | The employee is not covered by health | 21.83 | 25 | – Insure | – Ensure all employees apply medical insurance (BPJS) since the beginning of the recruitment |

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| | | | | | |
|---|---|---|---|---|---|
| | insurance | | | | |
| **E11** | Human-wildlife conflict occurred | 21.61 | 26 | – Avoid<br>– Mitigate | – Avoid planting palm and building mills in areas with a lot of wildlife<br>– Wildlife entering plantations is directed to their habitat |
| **S4** | Lack of employee training | 20.49 | 27 | – Prevent<br>– Cooperate | – Create regular employee training programs every few months<br>– Collaboration with training providers |
| **F1** | Bribery | 18.14 | 28 | – Prevent<br>– Cooperate | – Adoption of anti-corruption principles in running a company<br>– Collaboration with law firm every time law interpretation |
| **F7** | Transport for FFB is lacking | 16.86 | 29 | – Mitigate<br>– Prevent | – Add fleets to third party contracts<br>– Perform daily fleet forecasting needs every year |
| **F11** | The CPO stock did not match the results of the audit | 12.82 | 30 | – Reduce<br>– Prevent | – Perform routine stock calibration of CPO (Crude Palm Oil)<br>– Report daily CPO production according to reality |
| **E5** | Mill water use per ton of FFB is high | 12.51 | 31 | – Prevent | – Immediately repair any leakage of water and steam |
| **E4** | High BOD (biological oxygen demand) | 11.32 | 32 | – Reduce<br>– Prevent | – Use special chemical waste water according to the dose<br>– Gain oil regularly in cooling ponds |
| **E21** | Poor waste water treatment plant management | 10.67 | 33 | – Cooperate | – Collaboration with third party consultants on waste water management |
| **S7** | Inadequate education and health facilities | 10.19 | 34 | – Mitigate<br>– Prevent | – Provide special transportation for employees' children to the nearest government school area<br>– Enter in the following year's arrangement for the provision of schools and health facilities |
| **F10** | Unfair FFB Price | 10.07 | 35 | – Prevent | – Establish a policy that the company follows market prices |
| **E9** | Lack of conservation of habitat for endangered species around the company | 9.64 | 36 | – Cooperate | – Collaboration with government and NGOs in conservation programs |
| **E2** | Soil degradation | 8.75 | 37 | – Avoid<br>– Prevent | – Avoid planting oil palms close to rivers<br>– Use special techniques in managing estate on peatlands |
| **S10** | Employing underage children | 7.87 | 38 | – Prevent<br>– Mitigate | – Develop and apply responsible hiring policy<br>– Respond to negative report in time |
| **F6** | Tax Fraud | 7.12 | 39 | – Prevent<br>– Reduce | – Develop and compliance with Indonesia Laws<br>– Establish transparency policy |
| **E7** | Improper disposal waste | 4.70 | 40 | – Mitigate | – Make proper waste disposal |
| **E19** | Road construction is not in accordance with SOP | 4.63 | 41 | – Prevent | – Exercise strict supervision when making estate road |
| **F8** | Unplanned replanting | 3.98 | 42 | – Prevent | – Perform budgeting for replanting on annual capital expenditure |
| **F9** | Limited information and access to CPO marketing | 3.77 | 43 | – Mitigate | – Find potential buyers in new markets |
| **E18** | B3 waste management is close to the activities of the society | 2.30 | 44 | – Mitigate | – Move the B3 waste warehouse far from settlement |
| **F12** | Unplanned reclamation cost | 2.29 | 45 | – Prevent | – Carry out budgeting for damage estate |

## Results and Discussion

Sustainable supply chain risk management framework for palm oil industry in Indonesia presented here. Total 45 sustainability-related risk in supply chain of palm oil industry are identified. These sustainability-related risks categorized as: environmental, social, and economic/financial. RPN for each sustainability-related risk is calculated using fuzzy FMEA.

On one hand, four sustainability-related supply chain risk with risk priority number by using fuzzy linguistic (RPND) above 100 including low OER (153.03), looting of FFB (137.98), un-fulfill mill processing capacity (105.48) should be given the most attention. On the other hand, ten risk with RPND below 10 from lack of conservation of habitat for endangered species around the company (9.64) until unplanned reclamation cost (2.29) should be given less attention.

Based on rank of each category, three highest sustainability-related supply chain risk should be most important. From 21 environmental risks, 3 highest risk rank including operational in high conservation value (HCV) areas (6), greenhouse gases pollution (7), and land clearing by burning method (10), respectively. Then from 12 economic risk, 3 highest risk rank including low OER (1), un-fulfill palm oil mill capacity (3), and high cost of production (4), respectively. Finally, from 12 social risks, 3 highest rank is FFB looting (2), Improper working conditions (8), and high work accidents (9). The study provides a detailed methodology for manager and researcher to explore SSCRM framework for palm oil

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industry in Indonesia by using fuzzy FMEA with linguistic approach. Risk response is generic but the treatment specific for palm oil industry.

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## Conclusions

A number of sustainability-related risks in the supply chain of palm oil are identified from the RSPO and ISPO principles and criteria. Each risk with the FMEA fuzzy approach is analyzed and priority levels obtained for each risk where OER is low, looting FFB (Fresh Fruit Bunch), and mill processing capacity are not met are the three biggest risks, while the three lowest risks include limited information and access to marketing CPO, waste management B3 is close to population activities, unplanned reclamation costs. Each risk has a risk response and suggested more than one treatment, a combination of avoid, prevent, mitigate, cooperate, insure, reduce, retain, in detail in Table 7.

SSCRM framework for palm oil industry developed (Fig.2) in the final phase of this study. This framework has managerial implications which is by considering the empirical and completed study they can develop integrated sustainable supply chain risk management. They can start mitigate from higher risk until the lowest rank in Table 7.

This study has implications for the development theory and literature in sustainable supply chain risk management (SSCRM) field. However, it has also some limitations, the sustainability-related risk and risk treatment suggested are specific for palm oil industry and specific scope in Indonesia. Future study can use this study as a foundation to develop SSCRM framework in others industry. However, whoever wants to do study in palm industry better to wider the number of the object, including outside Indonesia. Another options, technique other than fuzzy FMEA should be advantage.

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