Supply Chain Risk Management Study of the Indonesian Seaweed Industry

Dissertation

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I would like to dedicate my dissertation to my husband, my daughter, and my parents.

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List of Abbreviations

ADB	Asian Development Bank
AHP	Analytical Hierarchy Process
ANP	Analytic Network Process
ATC	Alkali-treated *cottonii*
CRM	Customer relationship management
DEA	Data Envelopment Analysis
ELECTRE	Elimination and Choice Expressing Reality
E. cottonii	*Eucheuma cottonii*
ERMET	Ericsson Risk Management Evaluation Tool
EU	the European Union
E. spinosum	*Eucheuma spinosum*
FAO	the Food and Agriculture Organization of the United Nations
FDA	The US Food and Drug Administration
FMEA	Failure modes and effects analysis
GAIA	A Geometrical Analysis for Interactive Aid
GAP	Good Agricultural Process
GDP	Gross Domestic Product
GMP	Good Manufacturing Process
GTZ	Deutsche Gesellschaft für Internationalle Zusammenarbeit
GUI	Graphical User Interface
HACCP	Hazard Analysis and Critical Control Points
HAZOPS	Hazard and Operability Studies
HS	Harmonized System
IFC	International Finance Corporation, World Bank
IFC PENSA	International Finance Corporation Program for Eastern Indonesia Small and Medium Enterprise Assistance
IMP	Industrial Marketing and Purchasing
ISO	International for Organization Standardization
LCAs	Life Cycle Assessments
MCDA	Multi Criteria Decision Analysis
MADM	Multi Attribute Decision Making
MMAF, RI	Ministry of Marine Affairs and Fisheries, Republic of Indonesia
MSC	Marine Steward Council
NES	Not Elsewhere Specified
NGOs	Non-Governmental Organizations
PES	Processed *Eucheuma* seaweed
PNG	Philippine Natural Grade
PROMETHEE	Preference Ranking Organization Method for Enrichment Evaluation
RC	Refined-Carrageenan
RDS	Raw Dried Seaweed
SCM	Supply chain management
SCOR	Supply Chain Operations Reference Model
SCRMP	Supply Chain Risk Management Process
SMEs	Small Medium Enterprises
SRC	Semi-Refined Carrageenan
SRM	Supplier Relationship Management
TCE	Transaction Cost Economics
UNEP	United Nations Environment Program
UNCLOS	United Nations Convention on the Law of the Sea
UNCED	United Nations Conference on Environment and Development
WHO	World Health Organization

1 Introduction

1.1 Existing Conditions

As an archipelagic country, Indonesia is endowed with an abundance of tropical marine and coastal resources. The tropical marine and coastal ecosystems[1] are rich in biodiversity and provide one of the most productive resources for human life—including fisheries, coral reefs, mangroves, sea-grass beds, sandy marine, and estuarine environments; referred to as the *seascape* (Conservation International, 2008; Ferrol-Schulte et al., 2013; Moberg & Rönnbäck, 2003; Sala & Knowlton, 2006; United Nations Environment Programme/UNEP, 2006). The total area of Indonesia's sea is about 3,544,744 km^2, consisting of the territorial sea (284,210 km^2), the Exclusive Economic Zone[2] (2,981,211 km^2), and the 12-mile sea (279,322 km^2). The coastal line is 104,000 km. Its sea area is therefore larger than its land area (1,910,931 km^2).

Fisheries are part of the agricultural sector and play an important role in the national economy. In 2014, the fisheries subsector accounted for 22% of Indonesia's agricultural gross domestic product (GDP), only second behind food crops. Fisheries alone accounted for 3% of the total GDP, which grew on average by 7% p.a. from 2010 to 2014 based on the current market price. In 2013, the total production from capture fisheries and aquaculture was over 20 million tons, 70% of which came from aquaculture (Ministry of Marine Affairs and Fisheries, Republic of Indonesia, 2014a, 2014b). Thus, Indonesia is one of the largest seafood producers in the world.

The three main seafood commodities that were designed by the Ministry of Marine Affairs and Fisheries (MMAF), Republic of Indonesia are shrimp, tuna, and seaweed. The export volume and its value of shrimp and tuna have fluctuated from 2009 to 2013. During this period, the average export volume of shrimp increased by 3%, and its value grew by 16%. In contrast, the export volume and value of tuna declined, on average, by 8% in volume and 0.14% in value. Table 1-1 shows that there was a gradual rise in the export volume and value of seaweed, with volume increasing by 18% and value increasing by 19% from 2009 to 2013 (The United Nations Commodity Trade Statistics Database, 2009 -2013). It is therefore not surprising that Indonesia currently has the opportunity to become one of the largest seaweed producers in the world because of its large areas for seaweed cultivation (11,109 km^2). The total volume of production of seaweed during the 2009–2013 period increased by 30% on average (Ministry of Marine Affairs and Fisheries, Republic of Indonesia, 2014b).

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[1] An ecosystem is defined as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit' in the Biodiversity Convention (Gray, 1997, p. 157)

[2] The Exclusive Economic Zone (EEZ) is an area beyond and adjacent to the territorial sea in which a state has exclusive rights for exploring, exploiting, conserving and managing the natural resources. According to the third United Nations Conference on the Law of the Sea (1982), it shall not extend beyond 200 nautical miles from its coast.

Table 1-1: Export volume and its value of shrimp, tuna and seaweed from 2009 to 2013

Commodity	2009	2010	2011	2012	2013	2009-2013 [%]
Shrimp and prawn, frozen (Harmonized System or HS 030613)						
Volume [kg]	99,857,495	99,393,551	108,744,326	110,113,467	113,332,782	3
Value [US$]	693,881,868	790,572,834	997,506,693	970,566,455	1,219,534,300	16
Tuna nes (not elsewhere specified), fresh or chilled, whole (HS 030239)						
Volume [kg]	18,418,038	11,843,091	7,751,511	6,050,617	9,746,114	-8
Value [US$]	64,347,594	72,413,084	52,938,236	42,244,615	56,604,460	-0.2
Seaweed and other algae (HS 121220)						
Volume [kg]	94,002,964	123,074,961	159,075,454	168,279,322	176,110,739	18
Value [US$]	87,773,297	135,939,458	157,586,549	134,155,689	162,456,415	19

Source: The United Nations Commodity Trade Statistics Database (2009-2013)

Seaweeds, also known as marine macro algae, are classified into four main groups based on their pigmentation: *Rhodophyceae* or red algae, *Phaeophyceae* or brown algae, *Chlorophyceae* or green algae, and *Cyanophyceae* or blue-green algae (Glicksman, 1987; McHugh, 2003). Red and brown algae are mostly used for raw materials in the human and pet food industry because they produce three hydrocolloids[3]: agar, carrageenan, and alginate. They are also used for raw materials in the non-food industries, such as pharmaceuticals, cosmetics, textiles, paper, and bioenergy production. Hydrocolloids are essential ingredients in emulsifying and gelling agents, both in the food and non-food industries. However, several types of green and blue-green algae are used as salad ingredients.

The commercial types of red and brown seaweed can be widely found in Indonesia. The largest seaweed farming areas, especially for red algae, are in the eastern part of Indonesia, such as Sulawesi, Moluccas, Bali, and Nusa Tenggara Island. The most important species of red seaweed for commercial products include *Kappphycus alvarezii* or *Eucheuma cottonii* (*E. cottonii*), *Eucheuma dentilacum or E. spinosum*, and *Gracilaria*. *E. cottonii* and *E. Spinosum* are utilized for the carrageenan industry, whereas *Gracilaria* is used in the agar industry. *Sargassum* is the type of the commercial brown seaweed used as raw materials for alginate. The brown algae mostly cultivate in Java Island. The location of the red and the brown seaweed in Indonesia is depicted in Figure 1-1.

[3] Hydrocolloids or gums are ‘a diverse group of long chain polymers characterized by their property of forming viscous dispersions and/or gels when dispersed in water’ (Milani and Maleki, 2012, p.17).

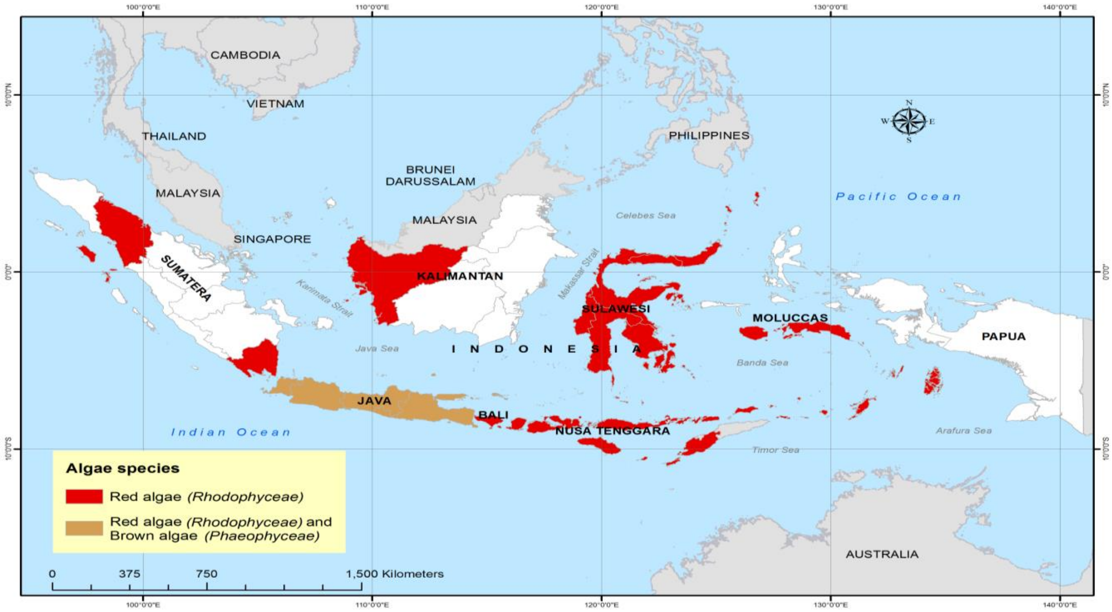


Figure 1-1: Location of red and brown algae in Indonesia

The global demand for seaweed is expected to increase in the coming years because of new product development using red algae. New product development is driven by the food industry such as for dairy applications, frozen desserts, and ice cream, which grew at 5.5% per year from 2006 to 2011. Dairy products are currently the market leaders for high-value products of seaweed, especially for those containing carrageenan. Pharmaceutical and household products are driving the non-food industry, but at a smaller volume of about 2% (CyberColloids Ltd., 2012). The demand for carrageenan and agar as raw materials, particularly for the food industry, is expected to increase in the future. Consequently, this additional demand will put more pressure on seaweed supply chains, which are categorised as agri-food supply chains.

Agri-food supply chains have rather different characteristics compared to other supply chains. These differences include limited shelf life of raw materials; fluctuating production due to biological processes; seasonal cultivation and harvesting; a complex physical product with sensory attributes such as taste, odour, appearance, colour, and size; uncertainty of demand and price; particular conditions for transportation and storage of raw materials and products; and specific consumer behaviour towards quality, product safety, animal welfare, and environmental friendly products (Aramyan, et al., 2006; Aramyan et al., 2007).

The specific characteristics of agri-food product chains contribute to supply chain risks. Today, seaweed supply chains face complex problems in both internal companies and external their networks. Disruptions of a seaweed supply chain, such as volatility of dried seaweed availability, can lead to downtime and an inability to meet the customers' timeline. Poor quality may have a negative impact on decrease customer's satisfaction in the long term. The volatility of seaweed prices also strongly influences profitability as price changes are difficult to transfer to the customer, resulting in a loss of profits. The industry also faces vulnerable and uncertain conditions caused by natural and man-made disasters.

1.2 Research Objectives

Supply chain disruptions lead not only to financial losses but also to non-financial problems such as a decrease in quality, reputation, and credibility. Hence, supply chain disturbances strongly influence the operating performance of firms and have a statistically significant effect on a company's long-term stock price and equity risk. The failure of managing supply chain risks creates conflict among the company's stakeholders such as investors, management, employees, suppliers, and customers. The effect of supply chain disruptions can also significantly influence the shareholder value because of production or shipment delays. As a result, firms would not be able to recover their financial performance in a determined period (Hendricks & Singhal, 2003, 2005a, 2005b).

Therefore, supply chain risk management is important part of the seaweed industry. Risks along seaweed supply chains, as well as the members' interdependence on each other, should be managed. If there are disturbances in one part of the supply chain, it affects the whole chain. In the future, risks will increase in the agri-food supply chain, requiring sound management to face complex and dynamic conditions. The range of seaweed applications is expected to increase in the future, and new product development using seaweed will continue over the years.

Long-term solutions need to be prepared to create a sustainable seaweed industry in Indonesia which also considers not only economic concerns but also environmental, social, and risk-related concerns. Therefore, the objective of this work is to develop a new reliable model for managing seaweed supply chain risks in Indonesia

This research attempts to design a model of seaweed supply chain risk management in Indonesia. The scope of this research focuses on the production of carrageenan and agar used in the food industry. The specific objectives of the thesis are:

1. Assessing the material flow of the carrageenan and agar supply chains using the software Umberto NXT Universal 7.0.
2. Identifying and categorizing the risks in the carrageenan and agar supply chain as well as investigating the causes and effects of the risks.
3. Assessing the risks within a carrageenan and agar supply chain in terms of the likelihood of occurrence and potential consequences.
4. Designing a new suitable model of seaweed supply chain risk mitigation using a decision support tool. The research presents alternative solutions using an analytical tool and framework to support decision makers of the seaweed supply chains.

1.3 Conceptual Framework

The concepts of supply chain and risk management have been merged into a new concept, namely supply chain risk management (Jüttner et al., 2003; Kersten et al., 2006, Sodhi & Tang, 2012; Zsidisin & Ritchie, 2009). There is a wealth of theoretical studies regarding supply chain risks and supply chain risk management. Supply chain risk becomes an increasingly popular research area (Jüttner, 2005; Peck, 2005; Ritchie & Brindley, 2007; Sodhi & Tang, 2012; Vanany et al., 2009).

A supply chain risk analysis is an assessment of failure by understanding the probability of occurrence that internal or external events could negatively affect the supply chain and disturb the flow of goods, information, and finance (Kersten et al., 2006; Norrman & Jansson, 2004; Pfohl et al., 2010; Zsidisin & Ritchie, 2009). Supply chain risk management is the process of managing risks in a supply chain by identifying and analysing the risks along the supply chain with several strategies, techniques, and tools to achieve supply chain sustainability through collaboration among the supply chain members.

There are many publications on supply chain risk management concepts, but few sources that have analysed the application of the concept. Literature on supply chain risk management has been increasing since the 2000s whereby most scientific papers propose a conceptual methodology for managing supply chain risks (Vanany et al., 2009). Papers with practical application of supply chain risk management include the aerospace sector (Raj Sinha et al., 2004), the mobile phone industry (Norrman & Jansson, 2004), the chemical industry (Kleindorfer & Saad, 2005), the automotive and electronic industries (Blos et al., 2009; Thun & Hoenig, 2011), the textile and clothing (Khan et al., 2008, 2009), and the food industry. Norrman and Jansson (2004) have further developed and implemented processes and tools for supply chain risk management in multinational provider of communication technology and services.

Empirical research of supply chain risk management in the agricultural field are limited to land-based agricultural products such as fresh vegetable and fruits (Merril, 2007), cocoa, dairy products, coffee, and maizes (Choudhary et al., 2011; Parizat et al., 2011; Ruther, 2009; World Bank, 2013). In terms of fishery products, Fitrianto and Hadi (2012) suggested a theoretical framework to conduct empirical research on the shrimp industry in Indonesia.

To fill the gap between theoretical and empirical research, this study focuses on seaweed as an important fishery/marine product. A comprehensive study of supply chain risk is useful for early identification of potential risks in seaweed supply chains and mitigation of the risks. In addition, it will provide managerial insight to decision makers of the seaweed supply chain and, in particular, to carrageenan and agar producers. The research framework is shown in Figure 1-2.

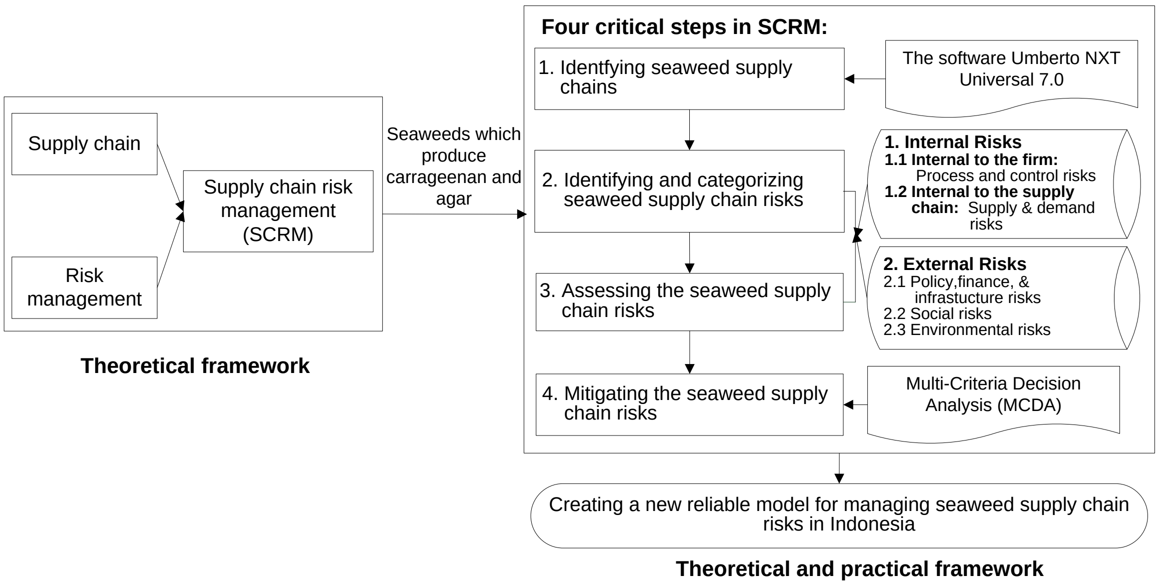


Figure 1-2: The research framework

This study proceeds in several steps. First, the carrageenan and agar supply chains in Indonesia are described. The following steps are similar to the risk management process, which consists of three crucial steps: risk identification and categorization, risk assessment, and risk mitigations (Faisal, 2009; Sodhi & Tang, 2012; Zsidisin & Ritchie, 2009). The paper is divided into seven chapters based on the research objectives. This chapter concerns with the background, research objectives, and the conceptual framework. The second chapter highlights seaweed farming, seaweed industry, and supply and demand of red seaweed.

In Chapter 3, the paper analyzes the seaweed supply chains in Indonesia. The key members of a seaweed supply chain are seaweed suppliers and seaweed manufacturers, carrageenan and agar companies. Supply of seaweed comes from seaweed farmers, local traders, and large traders who have the relative similar activities. Flow of material and energy in a seaweed supply chain was modelled by the software Umberto NXT Universal 7.0. The purpose of this process is to get a better understanding of the material and energy flow between the key members. Local and large traders act as middlemen bridging between seaweed farmers and seaweed manufacturers both in Indonesia and overseas.

In Chapter 4, risk identification, categorization, and assessment of seaweed supply chain risks are described. In this chapter, the theoretical reviews of risk management and supply chain risk management are also provided. Risk identification and categorization was conducted by the Delphi method classifying the risks into two main categories: internal and external risks. Internal risks are classified again into two classes: (1) internal company risks consisting of process and control risks and (2) external risks to the firm but internal risks to the supply chain network covering supply and demand risks. The external risks associated with the risks coming from the external network chain are risks concerning policies, finance, and infrastructure, as well as social and environmental risks (Christopher & Peck, 2004; Jüttner, 2005; Jüttner et al., 2003; Kersten et al., 2006). The goal of the risk identification and categorization is to verify the risk sources, the causes, and the impacts of the risks in the seaweed supply chain.

Based on the findings of risk identification, the risk assessment was conducted. The terms risk assessment, risk analysis, and risk estimation are used interchangeably in risk management literature. The purpose of this step is to analyse the likelihood and impact of an event, which is conducted by semi-quantitative analysis. Afterwards, the results are generated into a risk mapping. Following this process, the risk intensity was categorized based on the multiplication of likelihood and impact of an adverse event. The risk intensity is classified into five categories: negligible, marginal, critical, most critical, and catastrophic risks. This step is conducted to create a risk profile that assigns a significance rating to each risk, resulting in a prioritisation of the risks.

In Chapter 5, previous research studies on supply chain risk mitigation strategies are described. Based on the fourth chapter, a suitable model of risk mitigation strategies in a seaweed supply chain is defined using multi-criteria decision analysis (MCDA). The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) which belongs to MCDA is applied to assess risk mitigation strategies for a seaweed supply chain.

Finally, findings of this study are summarized. Furthermore, several possible future researches are recommended.

The data sources for this work are gathered using several approaches: field survey, in-depth interviews, and documentary analysis.

1. ***Field survey***
   This method provides an opportunity for the researcher to analyze the actual situation of seaweed supply chains in Indonesia. Initial data were obtained in April 2012 through semi-structured interviews of key stakeholders in Indonesia: the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, the Center for Coastal and Marine Resource Studies-Bogor Agricultural University, and the Indonesian Seaweed Association. The first survey gathered some general information related to seaweed farming and seaweed industry in Indonesia.

   Field research was conducted again in the following year (April–May 2013) to analyse the seaweed supply chain, to identify and categorize the sources of seaweed supply chain risk, and to assess the risks. Field surveys were conducted in Province of South Sulawesi (Makassar and Maros), East Java (Surabaya, Pasuruan, and Sidoarjo), West Java (Bogor and Bekasi), Banten (Cilegon), and West Nusa Tenggara (Mataram).

2. **In-depth interviews**
   In-depth interviews are the most widely used method in this line of research. It allows for greater investigation and understanding of supply chain flows and risk perspectives within the supply chain. In-depth interviews were guided by the questionnaires consisting of the questionnaire of flow of material and energy in a

seaweed supply chain, identification and categorization of seaweed supply chain risks, and assessment of the risks. A semi-structured interview was conducted, which refers to responsive, flexible, and interactive questioning techniques.

3. ***Documentary analysis***

This method involves the study of existing documents to understand their substantive content. Documentary sources are needed when situations or events cannot be investigated by direct observation or questioning. These may be public documents such as media reports, government reports, journals, and books. This research collected documents from the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, and the Indonesian Seaweed Association, as well as through desk research.

2 Seaweed Farming, Seaweed Industry, and Supply and Demand of Red Seaweed

We begin Chapter 2 by explaining seaweed farming describing the seaweed classification, seaweed cultivation methods, and seaweed cultivation history in Indonesia. Following this section, the seaweed industries covering carrageenan and agar industries are described. In the last section, supply and demand of red seaweed and their products are depicted. This section also provides information of global red seaweed supply, red seaweed supply in Indonesia, raw dried seaweed demand, and supply and market demand both for carrageenan and agar.

2.1 Seaweed Farming

2.1.1 Seaweed Classification

As mentioned in Chapter 1, seaweeds are classified into four groups: red algae, brown algae, green algae, and blue-green algae. The red and brown algae are generally used as raw materials for industrial purposes because they have polysaccharide content and can be produced in huge quantities. Blue-green algae are cultivated as an experimental source of protein. Seaweeds can also be categorized by their colloid content: *agarophytes*, *carragenophytes, and alginophytes. Agarophytes* produce agar which raw materials are *Gracilaria and Gelidium. Carragenophytes* produce carrageenan from *Kappaphycus alvarezii (Eucheuma cottonii*), *Eucheuma dentilacum* (*Eucheuma spinosum*), and *Hypnea* species. *Alginophytes* produce alginates from *Sargassum* and *Turbinaria.* The classification of seaweed or macro algae is shown in Figure 2-1.

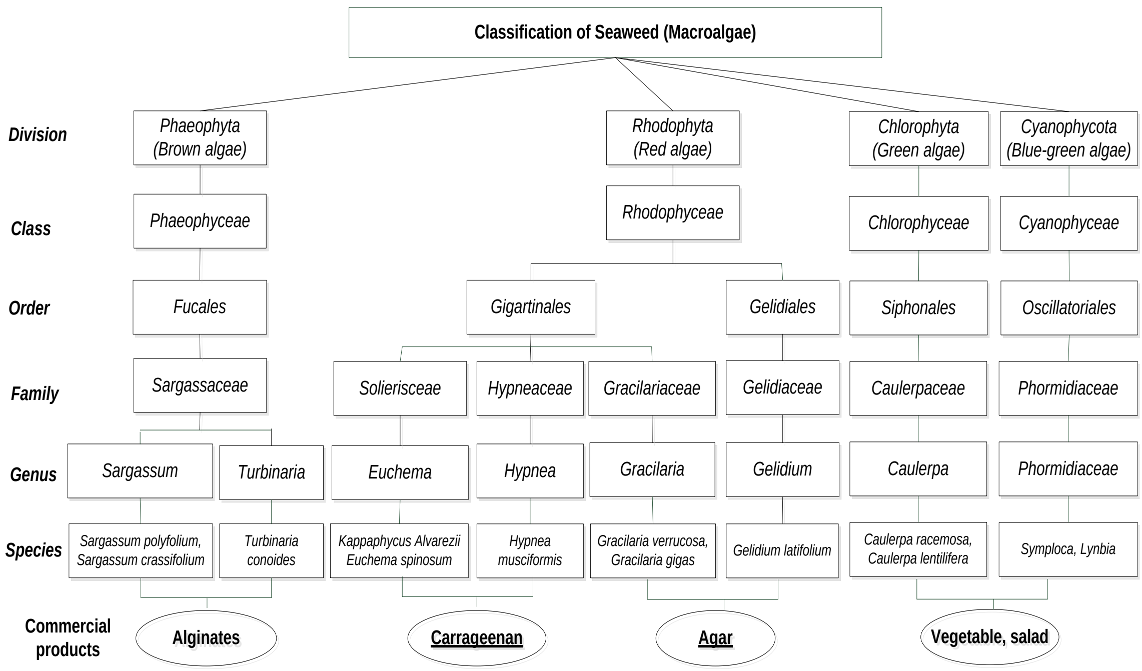


Figure 2-1: The classification of seaweed and their products
Source: Anggadiredja et al. (2006) and Nurdjana et al.(2009)

Red algae have historically been consumed as food in Asia and Europe. The red algae are used as raw materials for the hydrocolloid or gum industries producing carrageenan and agar, whereas brown seaweed produces alginates. Carrageenan, agar, and alginates are used as ingredients either food and non-food industry purposes, such as pharmaceuticals, cosmetics, textiles, and biofuel.

2.1.2 Seaweed Cultivation Method

Seaweed grows in sea-grass beds in coastal areas that are directly adjacent to the ocean. Seaweed is found in intertidal and sub-littoral zones with sand seawater, a little sludge, or a mix of them. Cultivation of seaweed is influenced by physiology resilience for adapting to external factors such as substrate, water salinity, water temperature at 25-30°C in shallow water near the beach, light, water movement, pressure, nutrients, and routine maintenance (Anggadiredja et al., 2006; McHugh, 2003).

Anggadiredja et al. (2006) and Surono et al. (2009) reported that a major determinant of successful seaweed cultivation is selecting an appropriate site. *E. cottonii* grows well on the upper side of the sub littoral zone, just below the low tide line of reef areas on sandy-corally to rocky substrates where the water flow level ranges from slow to moderate. In contrast, *Spinosum* thrives on sandy-morally to rocky substrates in areas that are constantly exposed to moderate to strong water currents (McHugh, 2003).

The standard requirements for an ideal location of *Eucheuma* cultivation are classified into oceanography and water quality parameters. The oceanography standards for deep sea should be 1–7m with a water flow of about 20 – 40 cm/second, substrates should be rocky sand and not muddy, and seaweed should be protected from big waves, storms and strong wind. The location should be away from shipping lines and free from pollution, and contact to light more than 1 meter. The water quality parameters comprise temperature at 26-32^{0}C, salinity at 28-34 parts per thousand (ppt), pH levels between 7-8.5, and organic content of more than 50 parts per million (ppm).

The cultivation method of *Eucheuma,* both *E. cottonii* and *E. spinosum,* employs three methods: off-bottom method, floating raft method, and long line method. The off-bottom method is usually implemented on a sandy bottom of sea water or muddy sand water. The floating raft method is applied in shell water where its movement is influenced by waves. The long line method or *rawai* is a method using long laid rope. This method is preferred by farmers in Indonesia and the Philippines because it is easy to obtain tools and materials at a lower cost than the other methods (Anggadiredja et al., 2006; Panlibuton et al., 2007). The cultivation method depends on regional circumstances. For example, the farmers in Bali Island prefer to cultivate seaweed using the off-bottom method, while farmers in South Sulawesi mostly use the long-line method. The three methods of seaweed cultivation of *Eucheuma* are presented in Figure 2-2.

Figure 2-2: The cultivation methods of E. cottonii and E. spinosum

Gracilaria use several cultivation methods: open waters on the bottom of bays, estuaries or reef flats, on lines, ropes or nets, in ponds, and tanks (McHugh, 2003). Most Indonesian farmers use a pond cultivation method that is supplied with both seawater and fresh water. Ponds need access to both salt and fresh water so that the salinity can be adjusted. The water also needs to be changed every two to three days (McHugh, 2003). The standard requirements for *Gracilaria* cultivation in a pond is described in Table 2-1. Frequently, *Gracilaria*, shrimp, and fish are cultivated in the same pond, called the mixed farming method. They act symbiotically, where the seaweed produces oxygen and protects fish or shrimp from predators. Shrimp and fish release impurities, which are used as nutrients by the seaweed.

Table 2-1: The standard requirements of Gracilaria cultivation in a pond

No	Parameter	Unit	Minimum Standard
A.	**Pond condition**		
1	Pond depths	m	0,5–1
2	The distance to the beach	m	300–1,000
3	Area condition		The pond near the freshwater source, free from pollution
4	Substrate	-	Sand and mud
5	Water change	-	Using tidal flows with different flows
B.	**Water Quality**		
1	Temperature	°C	20–28
2	Salinity	ppt (parts per million)	15–30
3	pH	-	6–9

Sources: Anggadiredja et al. (2006) and Nurdjana et al. (2009)

The reproduction of seaweed can be conducted in vegetative and generative processes. In vegetative reproduction, small amounts of seaweed are cultivated in an appropriate environment for their growth. They are grown to a suitable size so that they can be harvested, neither by removing the entire plant nor by removing most of it, but by leaving a small piece that will grow again. The seaweed is harvested after 45 days of cultivation. If the whole plant is removed, small pieces are cut from it and used as seedlings for the next cultivation.

Mature sporophytes release spores that germinate and grow into microscopic gametophytes in generative process. The gametophytes become fertile, and release sperm and eggs that join to form embryonic sporophytes. These slowly grow into the large sporophytes that can be harvested (Anggadiredja et al., 2006; McHugh, 2003). Indonesian seaweed farmers mostly cultivate their seaweed in a vegetative process.

2.1.3 Seaweed Cultivation History in Indonesia

The large variety of seaweed in Indonesia was collected by the Dutch oceanographic, Siboga and Snellius expeditions. The Dutch *Siboga* Expedition led by Max Carl Wilhelm Weber (March 1899 to February 1900), found more than 587 marine macro algae species in Indonesia. From 1929 to 1930, the Snellius-I expedition discovered additional seaweed species in Indonesia. Indonesia and the Netherlands started managing the Indonesian-Dutch Snellius-II Expedition from 1984 to 1985, which collected marine algae in the eastern part of Indonesia. They collected 1,750 seaweed herbarium specimens in Ambon, Maisel Island, Tukang Besi Island, Sumbawa, Komodo, Taka Bone Rate, and Salayer. At least 300 different species of seaweed had been identified to genus from this expedition (Coppejans & van Reine, 1989, 1992).These investigations offered valuable benefits to guide for seaweed cultivation areas in Indonesia.

Seaweed was largely used as traditional food in Indonesia in 1292 since the first European ships sailed through Indonesian sea. However, only fishermen consumed seaweed in forms such as salads, boiled as vegetables, and sweetened jellies. Other species of seaweed are utilized as herbal medicine (Soegiarto & Sulustijo, 1990).

Commercial seaweed usage started in the 1940s with trading and export of dried seaweed (*E. cottonii* and *E. spinosum*) from Makasar and Surabaya. Zaneveld (1959) identified five commercial uses of red algae from Indonesia including *Eucheuma, Gracilaria, Gelidium, Hypnea* and *Sargassum.* In 1967, Soerjodinoto and Hariadi Adnan cultivated *spinosum* seaweed in Pari Island and the Thousand Islands. In 1971, seaweed farming was successfully introduced in the Sulu archipelago by Maxwell S. Doty.

The first production of tropical seaweed aquaculture was started in 1974, when commercial quantities of *E. cottonii* were first produced in the Southern Philippines. Seaweed crop development was supported by the multinational carrageenan businesses: Marine Colloids, Cargill, and Copenhagen Pectin or CP Kelco (Neish, 2013) One year later, the Indonesian Institute of Science, *Lembaga Ilmu Pengetahuan Indonesia* or LIPI, began a project of *E. spinosum* cultivation in Samaringga and Rio Island in Sulawesi. In 1978, the cultivation of *E. cottonii* was supported by the Copenhagen Pectin Factory Ltd. in Nusa Lembongan, Nusa Penida, and Nusa Ceningan, Bali Island. However, the yield of carrageenan was low and the researchers tried to solve the problem by importing *E. cottonii* and *E. spinosum* seedlings from the Philippines in 1984 (Adnan & Porse, 1987).

Hans Porse introduced Indonesian seaweed species of *E. cottonii* and *E. spinosum* at the International Seaweed Symposium (ISS) I in Brazil in 1986. Seaweed was initially harvested from natural field environments in Indonesia. Since then, Indonesia has developed seaweed aquacultures, specializing in *Gracilaria, E. cottonii, and E. spinosum.*

Seaweed cultivation centers for both *Eucheuma* and *Gracilaria* are spread out in the eastern part of Indonesia, especially in Sulawesi Island. The centers of *Eucheuma* and *Gracilaria* cultivation are largely spread across the province of South Sulawesi, Central Sulawesi East Java, West Nusa Tenggara, and Banten. *Eucheuma* mainly grows in South Sulawesi, North Sulawesi, Bali, West Nusa Tenggara, East Nusa Tenggara, and Moluccas (Figure 2-3).

Indonesia is one of the largest *Gracilaria* producers in the world. Most of *Gracilaria* are cultivated in the waters of Banten, North Coast of Java (Serang, Tangerang, Bekasi, Karawang, Brebes, Pemalang, Tuban and Lamongan), South Sulawesi (Jeneponto, Takalar, Sinjai, Wajo, Paloppo, Bone, and Maros), and West Nusa Tenggara. The center of seaweed farming of *Eucheuma* and *Gracilaria* is shown in Figure 2-3.

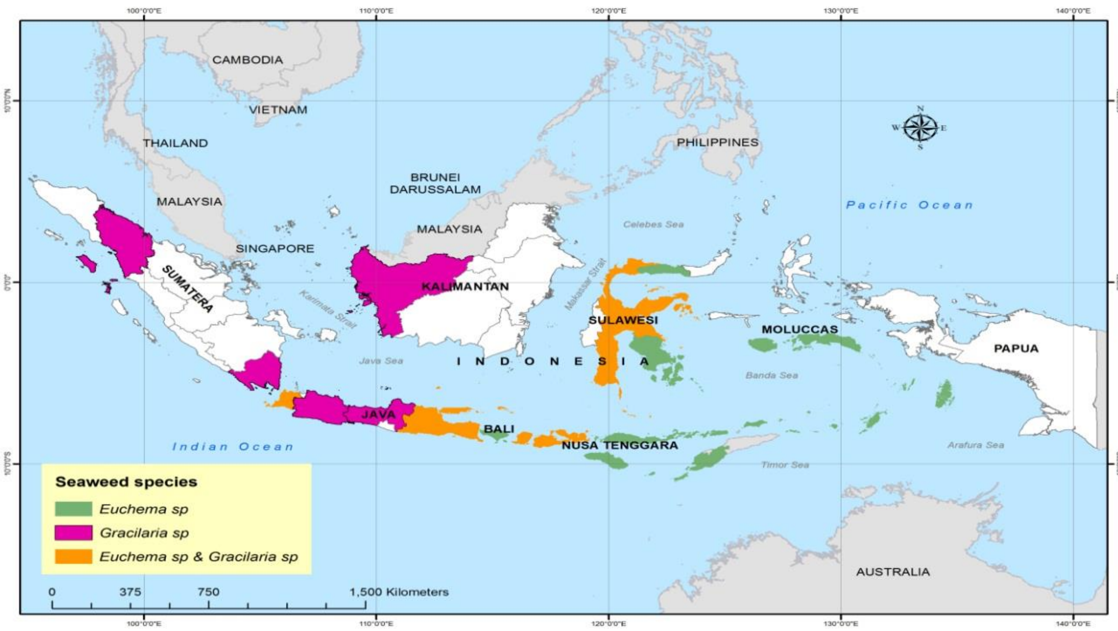


Figure 2-3: Center of seaweed farming of Eucheuma and Gracilaria in Indonesia

2.2 The Seaweed Industry

Carrageenan and agar have hydrocolloid contents. Hydrocolloids are built using long chain polysaccharide and proteins that have hydrophilic substances and dietary fiber. As Phillips and Williams (2009) stated, hydrocolloids come from the botanical, algal, microbial, and animal sources. They produce several hydrocolloids mostly used in food industries (see Table 2-2).

Table 2-2: Sources and types of commercially used hydrocolloids

No.	Sources of hydrocolloid	Types of hydrocolloids
1.	**Botanical**	
	Trees	Cellulose
	Tree gum exudate	Gum arabic, gum karaya, gum ghatti, and gum tragacanh
	Plants	Starch, pectin, cellulose
	Seeds	Guar gum, locust bean gum, tara gum, tamarind gum, and konjac gum
	Tubers	Konjac mannan
2.	**Algal**	
	Red seaweeds	Carrageenan and agar
	Brown seaweeds	Alginate
3.	**Microbial**	Xanthan gum, curdlan, dextran, gellan gum, and cellulose
4.	**Animal**	Gelatine, caseinate, whey protein, soy protein, egg white protein, and chitosan

Source: Phillips and Williams (2009)

Types of seaweed for alginate production are rarely cultivated in Indonesian water. Therefore, carrageenan and agar will be described further in the next section as potential seaweed industry in Indonesia. The different features of carrageenan, agar, and alginate are described in Table 2-3.

Table 2-3: The different features of carrageenan, agar, and alginate

Carrageenan	Agar	Alginate
Producing high-viscosity solutions and gels in water and high quality thermal gel formation	Insoluble in cold water but is soluble in boiling water	Cold water solubility
Reacts with proteins	Very strong brittle gel formation	Instantaneous calcium reactivity
Synergism with locust bean gum	Holds large amounts of soluble solids	Non-melting chemical gel formation

Source: Glicksman (1987)

2.2.1 Carrageenan Industry

Carrageenan is a water-based substitute for fats and oils (hydrocolloid) and is extensively utilized as an emulsifier, stabilizer, thickener, and gelling agent. The name of carrageenan is derived from the red seaweed types, *Carrageen Moss* or *Irish Moss*, in England and *Carraigin* in Ireland which has been used as a gelatin and for traditional healing since thousand years (Necas & Bartosikova, 2013). Therefore, carrageenan can substitute the functions of gelatin especially for vegetarians. The concentration of carrageenan is from 0.005% to 2% by weight in food products.

Carrageenan is an ingredient in food, various consumer goods, industrial products, and biotechnology applications. In a number of food utilizations, carrageenan can be found in human food, especially in dairy products, such as ice cream, chocolate milk, evaporated milk, milk puddings, processed cheese, water dessert gels, low-calorie jellies, and baby foods; as well as pet food. Consumer good uses of carrageenan include binders for toothpaste, thickeners for shampoos and cleaners, substances in skin cream and lotions, and air fresheners. Carrageenan is also used in industrial products such as for abrasives, pigments, pharmaceutical products, textiles, and agricultural agent solutions. Carrageenan can be also applied as an immobilize biocatalyst in biotechnology field (McHugh, 2003; Renn, 1986).

As a food additive, carrageenan is a high molecular weight linear polysaccharide comprising repeating galactose units and 3, 6-anhydro-D-galactose, both sulfated and non-sulfated, joined by alternating α-(1, 3) and beta β-(1, 4) glycosidic links. Therefore, carrageenan exhibits a high level of protein reactivity (Imeson, 2009; Panlibuton et al., 2007).

There are three main types of carrageenan: kappa, iota, and lambda. These types of carrageenan are distinct in their number and chemical composition or the position of the ester sulfate groups on both the α- and β-galactose units and the existence of 3, 6-anhydro-D-galactose in the chain, as depicted in Figure 2-4. The level of sulfate on the C-4 of the β-galactose units determines its gelling capability and solubility**.** A higher composition of sulfate causes carrageenan to be soluble at low temperatures lowering its gel strength (Anisuzzaman et al., 2013; McLachlan, 1985; Renn, 1986).

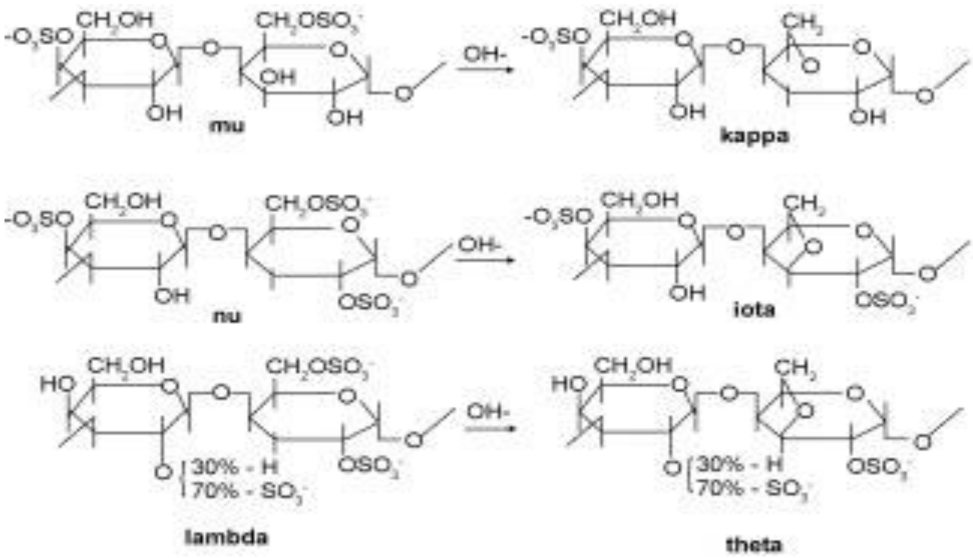


Figure 2-4: Carrageenan chemical structures (Imeson, 2009)

The first type of carrageenan, kappa carrageenan, is the most important raw material. Kappa carrageenan is widely used as a valuable ingredient in food additives and produces strong rigid gels when blended with water at 70°C and strong interaction with milk proteins. A blended solution between kappa carrageenan and potassium salts form strong, clear and thermoreversible gels.

The second type of carrageenan, iota carrageenan, is a group of carrageenan with intermediate content of an ester sulphate between kappa and lambda carrageenan. Gels of the iota carrageenan are more elastic and soft, as well as have reduced syneresis[4] and the ability to freeze and thaw.

The last form of carrageenan, lambda carrageenan, has the highest content of ester sulphate, which makes the creamy sensation in dairy products. Lambda carrageenan is non-gelling and interacts strongly with proteins. The ester sulphate of this type is randomly dispersed on the molecule, which inhibits gel creation and stimulates viscous suspensions. Kappa and lambda carrageenan are mainly utilized in the food industry, particularly in dairy products (Anisuzzaman et al., 2013; Glicksman, 1987; Imeson, 2009). The different characteristics for every type of carrageenan are described in Table 2-4.

Table 2-4: The specific characteristics of kappa, iota and lambda carrageenan

No.	Properties	Kappa carageenan	Iota carageenan	Lambda carageenan
1	**Ester sulfate (approximately)**	25–30%	28–35%	32–39%
2	**3,6-Anhydro-D-Galactose**	28–35%	30%	0%
3	**Solubility**			
	Hot water	Soluble above 70°C	Soluble above 70°C	Soluble
	Cold water	Na+ - salt soluble. Low to high swelling of K^+, Ca^{++}, and NH_4 salt		
	Hot milk	Soluble	Soluble	Soluble
	Cold milk	Insoluble	Insoluble	Disperse with thickening
	Cold milk plus tetra sodium pyrophosphate	Thickens or gels	Thicken or gels	Increased thickening or gelling
	Concentrated sugar solutions	Soluble hot	Difficulty soluble	Soluble hot
	Concentrated salt solutions	Insoluble cold and hot	Soluble hot	Soluble hot
	Organic solvents	Insoluble	Insoluble	Insoluble
4	**Gelation**			
	Effect of cations	Gels most strongly with K^+	Gels most strongly with	Non-gelling
	Type of gel	Elastic with syneresis	Elastic with no syneresis	Non-gelling
	Locus bean gum effect	Synergistic	None	None
5	**Stability**			
	Neutral and alkalin pH	Stable	Stable	Stable
	Acid (pH 3.5)	Solutions hydrolyzes	Accelerated by heat	Hydrolyzes
		Gelled state stable		

Source: Glicksman (1987)

Kappa, iota and lambda carrageenan are obtained from red algae but not from the same species. Kappa carrageenan is obtained primarily from *E. cottonii* while iota carrageenan is derived from *E. spinosum*. *Chondrus chrispus* is the main source of lambda carrageenan (Imeson, 2009). These types have carrageenan content in their cell wall and the intercellular matrix of the plant tissue whose the content is about 30-80% of its dry weight. Red seaweed for producing lambda carrageenan is rarely cultivated in Indonesia.

[4] Syneresis is the separation of a liquid from a gel such as the collection of whey on the surface of yoghurt

2.2.2 Agar Industry

Agar was the first hydrocolloid used as food additives in the Far East over 300 years ago. Payen (1859) introduced agar as a food ingredient in the West, and then Koch (1882) presented agar as a product with microbiological applications. Afterwards, Smith (1905) and Davidson (1906) introduced wider applications of agar and its production in Japan; China and Korea followed soon after with *Gelidium* as a raw material (Armisen & Galatas, 2009).

Agar is made from red seaweed, mainly obtained from *Gracilaria, Gelidium, Pterocladia, Acanhopeltis*, and *Ceramium*. However, *Gracilaria* is most commonly used for producing agar. The species of *Gelidium* and *Pterocladia* provide a better quality agar, but they have not been widely cultivated yet; they grow in the open sea. With a cultivation time of one year, *Gelidium* has longer cultivation time than the other types, such as *Gracilaria*.

Agar has one of the strongest gels of hydrocolloid products; its chemical structure is characterized by repetitive units of D-galactose and 3-6, anhydro-L-glactose, with few variations, and a low content of sulphate esters (Armisen et al., 2009). For this reason, agar is insoluble in cold water but is soluble in boiling water. Agar is composed of at least two polysaccharides: agarose and agaropectins. Agarose is used for industrial purposes as food ingredients because they have gelling abilities, whereas agaropectins lack practical applications. Figure 2-5 shows the chemical structure of agarose.

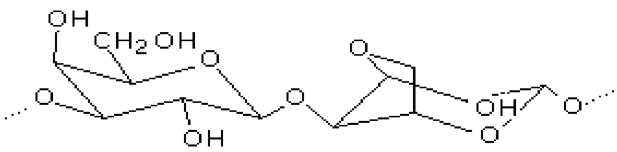


Figure 2-5: Chemical structure of agarose
Source: Cybercolloids (2012)

Agar is widely used for food production (90% of agar use) in bakery products, canned meats, confectionery, and miscellaneous; the remaining 10% is used for bacteriological and biotechnology practices (McHugh, 2003). Agar is used as a stabilizer in bakery products such as chiffon pies, meringues, and filled cakes. Gelling agents of agar are used to avoid damaging of canned meat and fish, primarily in Europe and Japan. Jellied candies, marsh mallows, and other confectionery products are made of agar and other ingredients. Agar is also used as a binding agent in vegetarian and health foods and gelling properties in jelly desserts, puddings, and preserves (Becker & Rotmann, 1990; Glicksman, 1987).

Today, there are also various alternatives to agar in products such as starches, pectin, and gelatine. Some non-food applications of agar are as smooth laxatives in the pharmaceutical industry and growth substrate to clone specific plants, such as orchid. A gelatinous substance of agar is applied in the preparation of growth media for culturing various bacteria and fungi in the biotechnology field (Armisen & Galatas, 2009; McHugh, 2003).

There are two different types of agar: natural and industrial agar. Natural agars have been produced by artisans and lack quality control, but they are still suitable for home cooking. The second type is manufactured in modern plants and is utilized as an industrial food ingredient, and it needs high-quality control. Square agar, strip agar, and flake agar are usually used as natural agar, whereas powdered agar is labelled as industrial agar (Becker & Rotmann, 1990). The type of agars, their applications, and sources of seaweed are shown in Table 2-5.

Table 2-5: Types of agar, their applications, and sources of seaweed

Type of agar	Application/s	Source/s of seaweed
Natural agar	Strip	*Gelidium*
	Square	
	Used mainly in Far East cooking customs	
Industrial agar	Food grade agar used for industrial food production	*Gelidium, Gracilaria, Pterocladia, Ahnfeltia, Gelidiella*
	Pharmacological agar	*Gelidium*
	Clonic plants production grade	*Gelidium or Pterocladia*
	Bacteriological grade used for bacteriological media	*Gelidium or Pterocladia*
	Purified agar used in biochemistry and in media for very difficult bacteria	*Gelidium*

Source: Armisen and Galatas (2009)

2.3 Supply and Demand of Red Seaweed and Their Products

This section provides information related to supply and demand of commercial red seaweed. It also describes supply and demand of carrageenan and agar.

2.3.1 Global Supply of Red Seaweed

Global red seaweed production has increased significantly over the past years, specifically *E. cottonii* and *Gracilaria.* The global production of *E. cottonii* in 2011 is estimated at 198,350 tons. Indonesia is currently the largest producer of *E. cottonii* in the world. Production of *E. cottonii* in the Philippines is substantially smaller than in Indonesia, which has decreased by 27% since 2006 (Figure 2-6). This is due to weather conditions and political will of seaweed farming in the Philippines. It implies that future suppliers of *E. cottonii* will most likely come from Indonesia.

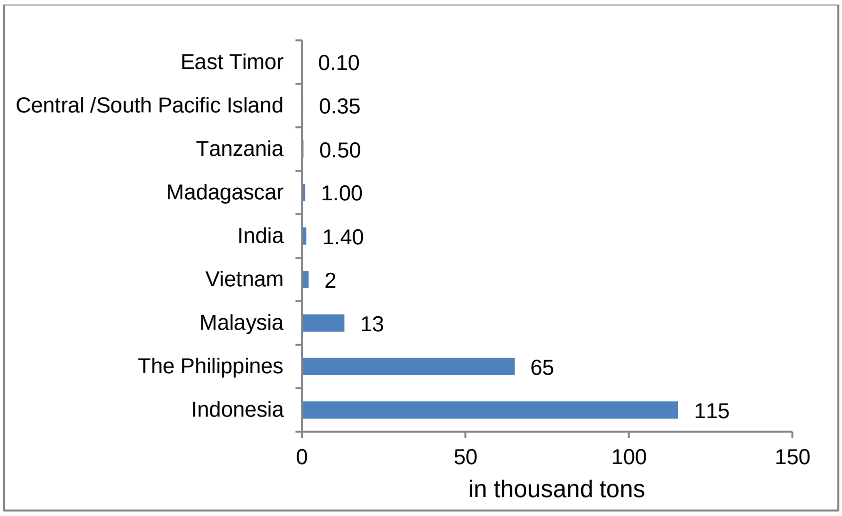


Figure 2-6: Estimated global production of E.cottonii in 2011

Source: CyberColloids Ltd.(2012)

E. cottonii, which produces kappa carrageenan, has the highest yield among other types such as *spinosum, gigartina*, and *chondrus*. From 1999 to 2009, the production of *E. cottonii* in Indonesia, the Philippines, Malaysia, and Tanzania increased by 22.14%, while the other types rose by less than 15% during this period (see in Table 2-6).

Table 2-6: The geographic harvest of Eucheuma in the world

Type	Major countries	Extract type	1999 harvest [dry tons]	2009 harvest [dry tons]
E.Cottonii	The Philippines, Indonesia, Malaysia, Tanzania	Kappa	131,000	160,000
Spinosum	The Philippines, Indonesia, Tanzania	Iota	20,000	23,000
Gigartina	Chile, Malaysia, Peru, Mexico	Kappa	13,000	15,000
Chondrus	Canada, USA; France, Spain, Portugal, Korea	Kappa	4,000	4,500
Total			168,000	202,500

Source: Bixler and Porse (2011)

2.3.2 Supply of Red Seaweed in Indonesia

Indonesia provides an optimal environment for cultivating red seaweed because it has a tropical marine climate with average sea temperatures of about 25 to 30°C. From 2007 to 2011, there was a slight increase in the production of *Eucheuma* in Indonesia. *Eucheuma* production is greater than *Gracilaria production*; from 2007 to 2011, production of *Eucheuma* was approximately seven to nine times higher than that of *Gracilaria*. For example, *Eucheuma* production in 2011 was 4,623,754 wet tons while *Gracilaria* production totalled 682,611 wet tons[5]. Although there was a significant difference of production, the growth of production of both *Eucheuma* and *Gracilaria* was similar at 31–36 per year from 2004 to 2011 (Figure 2-7).

[5] 1 wet ton of *E. cottonii* is equal 0.125 – 0.17 ton raw dried seaweed of *E. cottonii*, while 1 wet ton of *Gracilaria* is equal 0.10 ton raw dried seaweed of *Gracilaria.*

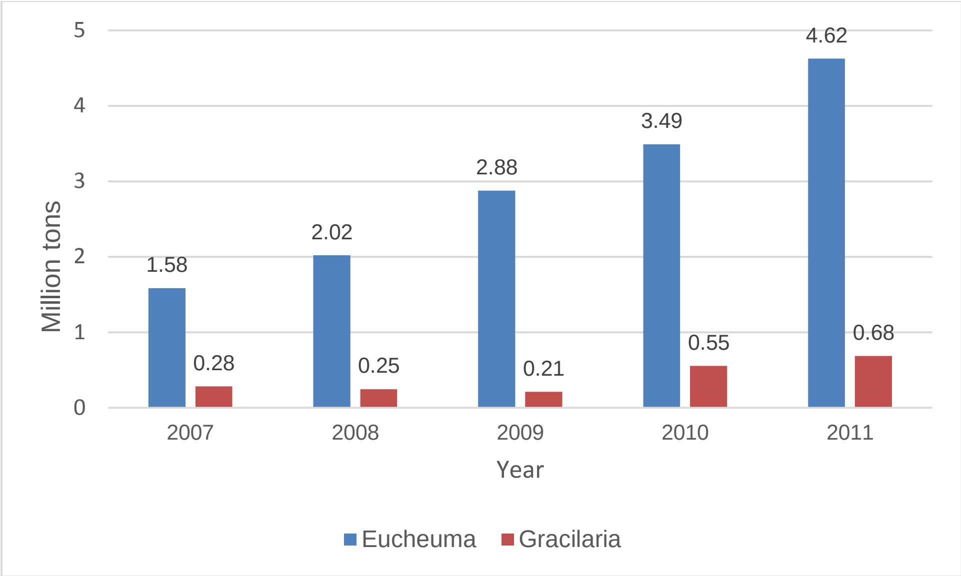
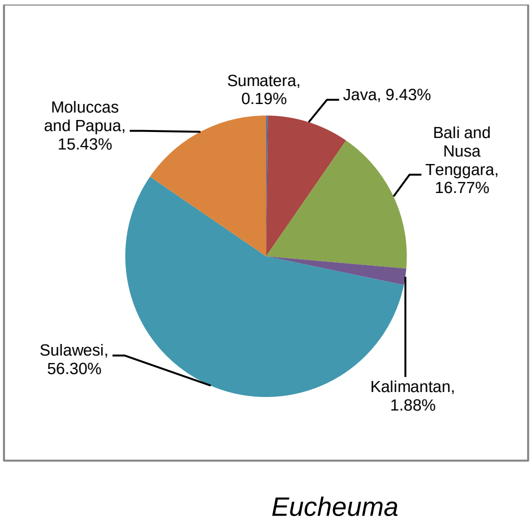


Figure 2-7: Production of Eucheuma and Gracilaria from 2007 to 2011 in Indonesia
Source: Ministry of Marine Affairs and Fisheries (2012)

Many studies indicate that the distribution and density of seaweed in different regions vary due to the type of bottom, season, hydrographic conditions, and species composition at specific times (Soegiarto & Sulustijo, 1990). As described in Figure 2-8, Sulawesi Island is the largest region that produces both *Eucheuma* and *Gracilaria* in numerous locations such as South Sulawesi, Central Sulawesi, and Southeast Sulawesi. The production volume and value of *Eucheuma* and *Gracilaria* in the ten largest regions of seaweed cultivation is shown in Table 2-7.



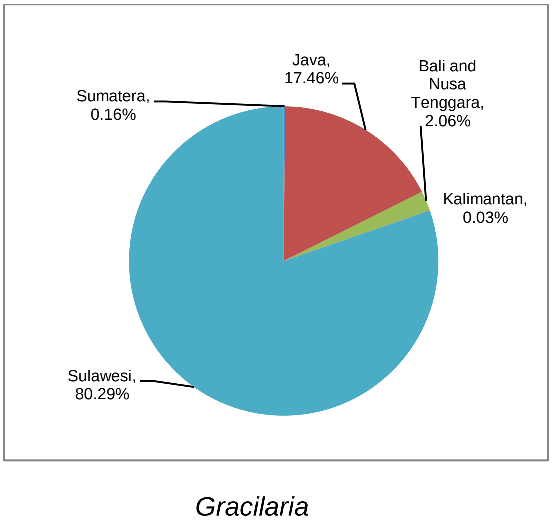


Figure 2-8: The percentage of production of Eucheuma and Gracilaria in Indonesia, 2011

Table 2-7: Production and value of Eucheuma and Gracilaria in the ten major area of seaweed cultivation

No	Province	Production [wet tons]	Percentage [%]	Value [Euro]*
Eucheuma: Cottonii and Spinosum				
1.	South Sulawesi	1,024,302	24	129,441,000
2.	Central Sulawesi	734,381	17	136,112,000
3.	Moluccas	610,365	14	128,553,000
4.	Southeast Sulawesi	586,965	14	148,349,000
5.	East Java	409,536	10	34,502,000
6.	East Nusa Tenggara	377,200	9	111,222,000
7.	West Nusa Tenggara	277,700	7	35,092,900
8.	Bali	106,398	3	31,372,800
9.	Gorontalo	89,149	2	15,021,000
10.	Banten	13,337	0.3	786,517
Gracilaria				
1.	South Sulawesi	481,962	77	40,603,600
2.	Banten	41,903	7	4,822,840
3.	Central Java	39,465	6	4,987,180
4.	Central Sulawesi	24,529	4	2,066,480
5.	West Java	21,955	4	1,849,660
6.	West Nusa Tenggara	13,000	2	696,775

Source: Ministry of Marine Affairs and Fisheries of the Republic of Indonesia (2012)

**Currency converter by Oanda.com per 30 April 2013*

2.3.3 Demand of Raw Dried Seaweed

The global demand for raw dried seaweed, especially for *E.cottonii* types, is growing because of the increased carrageenan processing, especially in China. Most Indonesian raw dried seaweed is currently processed in China (Figure 2-9).

The future market for *E. cottonii* is tied to the future demand for the carrageenan that is extracted from it. *E. cottonii* can be processed into semi-processed materials, such as alkali-treated carrageenan (ATC) in chip shapes, semi-refined carrageenan (SRC), and refined carrageenan (RC) in powder forms.

The other types of red algae*, Gracilaria*, *Gelidium, Hypnea*, and *Gelidiella*, are the sources for industrial food-grade agar. Most agar companies in Indonesia use *Gracilaria sp.* as raw materials for their production because it is widely available in Indonesian waters and is easy to cultivate in a pond. *Gracilaria* is normally sold to agar producers or used as traditional food.

China has been the largest producer of seaweed products worldwide since 2009. From 2009 to 2013, China and the Philippines were the top importers of raw dried seaweed from Indonesia, both for *E.cottonii* and *Gracilaria*. In both countries, there are many carrageenan and agar manufacturers.

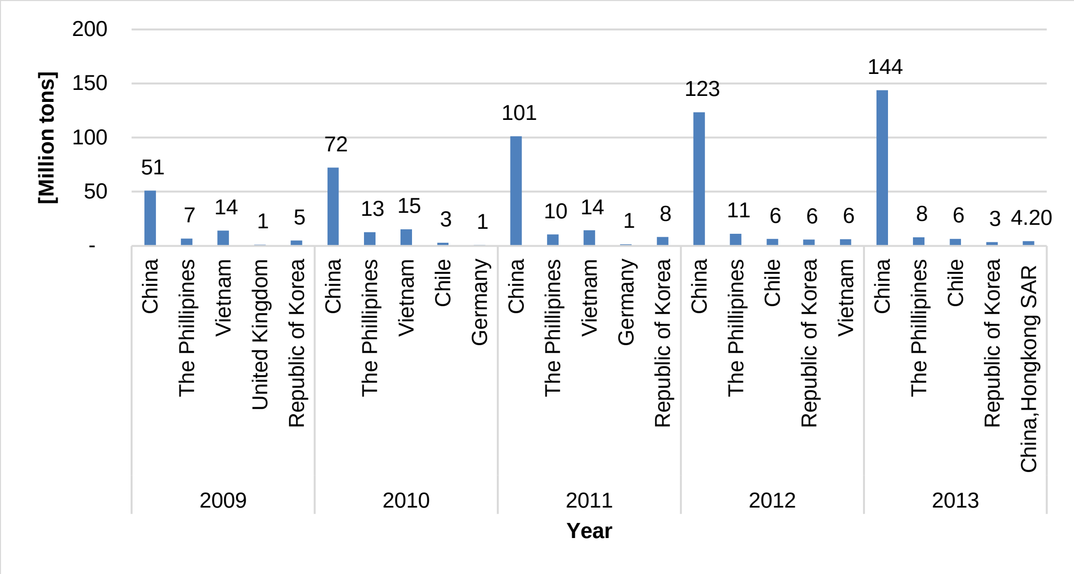


Figure 2- 9: Volume export of Indonesian seaweed to the top five countries from 2009 to 2013

Source: The United Nations Commodity Trade Statistics Database (2009 -2013)

Sales volume of hydrocolloids in the world from 1999 to 2009 increased by 18%, where agar sales grew by 28%, alginates by 15%, and carrageenan by 19%. The sales value of carrageenan is currently the highest (81%) among agar and alginates from 1999 to 2009. This can be seen by the increase in the average price of carrageenan by 50% in this period (Table 2-8).

Table 2-8: Sales volume, sales value, and price of carrageenan, agar, and alginates

Seaweed hydrocolloid	**1999**			**2009**		
	Sales volume [tons]	**Sales value [million US$]**	**Average price [US$ kg^{-1}]**	**Sales volume [tons]**	**Sales value [million US$]**	**Averages price [US$ kg^{-1}]**
Carrageenan	42,000	291	7	50,000	527	10.5
Agar	7,500	128	17	9,600	173	18
Alginates	23,000	225	9	26,500	318	12
Total	*72,500*	*644*		*86,100*	*1,018*	

Source: Bixler and Porse (2011)

2.3.4 Supply and Demand of Carrageenan

The Asia-Pacific region is the major producer of carrageenan in the world. Over 70% of carrageenan capacity is located in Asia-Pacific. China currently dominates the production of semi-refined carrageenan using gel press technology. Alcohol precipitation production is concentrated in Europe and the US. The key players of carrageenan companies in the world are Ceamsa (Spain), CP Kelco (Denmark), Cargill (France), FMC corporation (the US), Gelymar (Chile), MSC Co.Ltd., (Korea), Mitsubishi (Japan), and Shemberg Biotech (Japan). The production volume of different carrageenan types and its geographic origin from 1999 to 2009 are listed in Table 2-9.

Table 2-9: The geographic distribution of carrageenan production

Region	Refine carrageenan [tons]		Semi-refined carrageenan [tons]		Total
	Alcohol	Gel press	For human food	For pet food	
1999					
Europe	7,700	2,500	200	-	10,400
Americas	4,800	2,000	-	-	6,800
Asia-Pacific	1,000	3,000	8,000	11,000	23,000
China		1,000	1,000		2,000
Total production	13,500	8,500	9,200	11,000	42,200
Total capacity	15,200	11,000	12,000	13,000	55,200
Percent utilization [%]	*88*	*77*	*77*	*85*	*76*
2009					
Europe	6,000	1,000	100	-	7,100
Americas	4,500	3,500	1,400	-	9,400
Asia-Pacific	1,000	4,000	16,000	5,000	26,000
China		4,500	3,000	-	7,500
Total production	11,500	13,000	20,500	5,000	50,000
Total capacity	13,500	16,500	27,000	8,000	65,000
Percent utilization (%)	*85*	*78*	*76*	*65*	*76*

Source: Bixler & Porse (2011)

Industrial Market Research International predicted that global demand for carrageenan will rise about 4–6% every year. The demand for carrageenan is approximately 90%. Worldwide sales of carrageenan are estimated to be around $640 million and have increased by 36% in value but only by 6% in volume. This condition influences the continued growth of carrageenan use in meat (3.5%); dairy, frozen desserts, and ice cream (5.5%); growth for jellies (5.5%), and other segments (2%) (CyberColloids Ltd., 2012).

In the 2006–2011 periods, more new products that contain semi-refined carrageenan (E407a) were launched worldwide than products containing refined carrageenan (E407). However, the use of E407a in dairy applications has decreased significantly since 2006, whereas their uses in all other categories increased. It may reflect a change in taste where dairy applications typically have more delicate flavours than savoury products. Most of the new product development activity in the food industry is represented by six end-use products: desserts and ice cream; dairy; processed fish, meat, and egg; meals; bakery; and snacks. Desserts and ice cream are dominating the activity. For example, new product development activities containing semi-refined carrageenan (E407a) for desserts and ice cream increased 50.5% from 2006 to 2011 (Table 2-10).

Table 2-10: New product development activities by application containing refined carrageenan (RC) and semi-refined carrageenan (SRC) in the periods 2001–2006 and 2006–2011

End use product	2001 – 2006		2006 - 2011	
	RC (E407)	SRC (E407 a)	RC (E407)	SRC (E407 a)
Desserts and ice cream	43.0 %	51.2%	36.9 %	51.0%
Dairy	18.5 %	22.4%	22.0 %	4.1%
Processed fish, meat and egg	7.0 %	10.4%	8.8 %	17.4%
Meals and meals centers	6.9 %	8.0%	7.1 %	21.4%
Bakery	5.2 %	0.8%	4.0 %	2.55%
Snacks	2.8 %	1.6%	2.6 %	3.0%

Source: CyberColloids Ltd. (2012)

The greatest change in new product development containing carrageenan occurred in Europe from 2001 to 2011. In this period, there was an increase in research on carrageenan product development. There was also a substantial increase in new product development activity in Asia-Pacific and Latin America from 2001 to 2006.

Because of their thickening, carrageenan as a gelling agent is very essential for the food sector. They are used widely in products such as salad dressing and sauces as emulsifiers, in beer to enhance foam, and in bakery icing to counteract stickiness and cracking. The use of semi-refined carrageenan (SRC) has traditionally been more common in Asia, and its demand increased in Europe from 2006 to 2011. During this period, most of the new products containing SRC were launched in Europe and dominated the carrageenan market (Table 2-11).

Table 2-11: Global new product development by region containing refined carrageenan (RC) and semi-refined carrageenan (SRC) in the periods 2001–2006 and 2006 –2011

End use product	2001 – 2006		2006 - 2011	
	E407	E407a	E407	E407a
Asia Pacific (including Australia and New Zealand)	12.9 %	76.0%	18.3 %	39.8%
Europe	40.6 %	22.4%	41.0 %	55.6%
Latin America	8.2 %	0.8%	13.0 %	1.2%
Middle East and Africa (including South Africa)	3.2 %	0.0%	3.1 %	2.2%
North America	35.1 %	0.8%	24.6 %	1.2%

Source: CyberColloids Ltd. (2012)

China is the world’s largest exporters of carrageenan, with a growth value of 75% from 2010 to 2013. The second largest country which exports carrageenan in this period was Germany, with a growth of 36%. Chile, France, and the US have also been among the top three exporters worldwide. The total export value of carrageenan was US$ 968,880,910 in 2013 with the growth value of 42% in the five years preceding.

Denmark is recorded as the first major importer of carrageenan, with 47% growth from 2010 to 2013. The country is also known as a significant producer of carrageenan because of their famous carrageenan companies such as Eurogum, Danisco (Dupont), Algadan, and Poly Agar. Germany, Mexico, and the US were the key importers of carrageenan from 2010 to 2013. Detailed values of carrageenan exports and imports from 2010 to 2013 are presented in Table 2-12.

Table 2-12: Value of export and import of carrageenan (HS code 130239) worldwide from 2010 to 2013 in US$

Exporters/ Importers	2010	2011	2012	2013	Average annual growth rate [%]
Top Exporters					
China	203,581,595	249,876,043	293,262,018	356,046,867	21
The US	70,804,444	77,544,084	91,968,964	83,360,132	6
France	67,496,227	78,238,645	74,918,396	80,195,873	6
Chile	52,069,148	54,416,362	58,160,874	70,792,806	11
Germany	50,056,478	54,014,535	59,992,444	68,137,995	11
Other countries	239,638,743	262,814,931	297,986,120	310,347,237	9
Total Export	**683,646,635**	**776,904,600**	**876,288,816**	**968,880,910**	**12**
Top Importers					
Belgium	96,400,036	51,870,193	58,082,841	54,184,811	- 14
Germany	93,027,733	107,316,377	101,481,610	115,295,602	8
The US	92,381,728	100,911,149	102,898,938	99,279,558	3
Mexico	41,042,564	42,741,788	49,750,179	47,691,753	5
Denmark	40,686,923	45,734,069	52,202,367	59,916,791	14
Others	482,376,460	569,837,127	585,776,527	614,561,374	9
Total Import	**845,915,444**	**918,410,703**	**950,192,462**	**990,929,889**	**5**

Source: United Nations commodity trade statistics database (2014)

Indonesia’s export volume of carrageenan has changed dramatically from 2011 to 2012, which increased by nearly 300%. The growth of carrageenan manufacturing seems to be the main driver of the increase in production. The average export growth between 2010 and 2013 climbed, with an average of 92% per year. Indonesia’s carrageenan imports declined during the last five years, reflecting the fact that many carrageenan processors were built in this period. A record of export and import volume of Indonesia’s carrageenan from 2010 to 2013 is summarized in Figure 2-10.

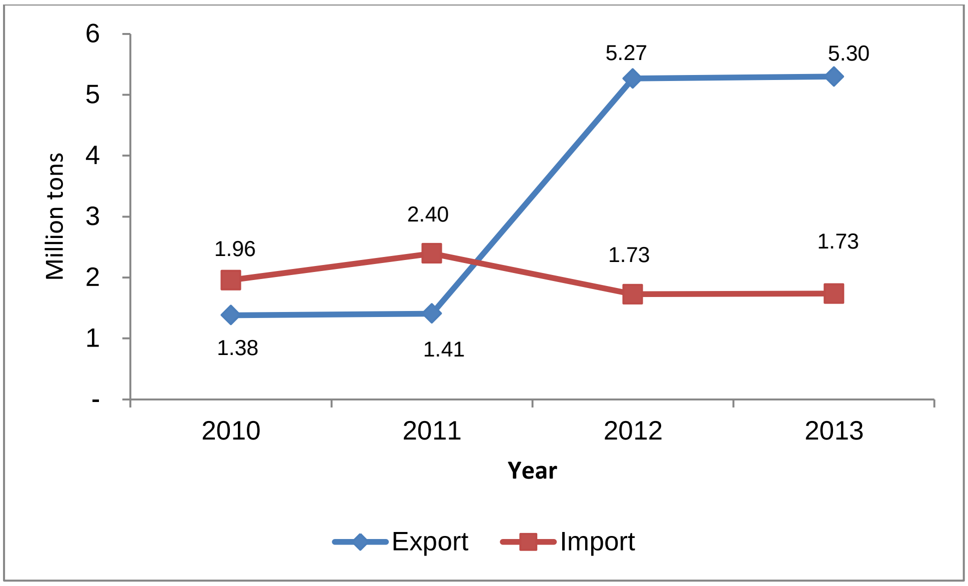


Figure 2-10: Volume of export and import of Indonesia's carrageenan from 2010 to 2013
Source: United Nations commodity trade statistics database (2014)

2.3.5 Supply and Demand of Agar

Understanding the market and demand trend of seaweed products, carrageenan and agar, is essential for assessing the seaweed supply chain. Countries in the Asia-Pacific region are the largest producer of agar in the world (42%). Currently, Indonesia and Chile emerge as market leaders of agar production which collectively produces about 3,600 tons per year. Globally, the total production of agar increased of 28% over ten years, from 1999 to 2009. Agar production for each region in the world is shown in Table 2-13.

Table 2-13: Volume of agar production in the world in 1999 and 2009

No	Region	Volume in 1999 [tons]	Volume in 2009 [tons]
1	Europe	1,000	700
2	Africa	900	800
3	Americas	2,600	2,800
4	Asia-Pacific	3,000	5,300
Total production		7,500	9,600
Total capacity		9,000	12,500
Percentage of utilization		83%	77%

Source: Bixler & Porse (2011)

The agar market is relatively stable and is not likely to grow by much, although new approaches are being developed. This is because agar has been substituted by other hydrocolloids that produce better and cheaper products (McHugh, 2003). The volume of water gels that dominate the agar market segmentation increased by 16% from 1999 to 2009 (Table 2-14).

Table 2-14: Volume of agar market segments (tons)

Market segment	1999	2009
Confection (water gels)	2,800	3,250
Baking	2,300	2,800
Retail (gel powder)	1,200	2,000
Meat	200	150
Other (dairy product)	300	500
Bacto/ pharmacy /agarose	700	900
Total	**7,500**	**9,000**

Source: Bixler & Porse (2011)

China is also the world's largest producer of agar, from 2010 to 2013, produced an export value of 69 million US$, where the growth value was 60%. Countries such as Republic of Korea, Spain, Chile and Indonesia have accelerated the rate of production for which the export value of agar has increased by 20 to 37% (Table 2-15).

Japan is the largest importer of agar, mainly from Indonesia and Chile. Some buyers, particularly from Japan, are now buying raw dried seaweed and alkali-treated *Gracilaria*. Shipping agar to Thailand and the US from other countries increased by an average of 23% during the period 2010 to 2013. Spain and France were also top importers of agar during this period, where the growth of import value was 33%. The European Union lists agar products as food additives, and they are labelled as E406. Table 2-15 describes the value of export and import of agar from 2010 to 2013.

Table 2-15: The value of export and import of agar (HS code 130231) worldwide from 2010 to 2013 in US$

Exporters/ Importers	2010	2011	2012	2013	Average annual growth rate [%]
Top Exporters					
China	43,016,832	53,825,796	58,803,290	69,064,912	17
Chile	36,469,389	43,638,601	43,804,793	44,069,582	7
Spain	22,440,044	21,501,433	23,407,705	29,535,676	10
Germany	14,155,153	14,637,048	9,453,508	12,854,715	1
Indonesia	10,693,156	12,627,490	12,861,057	13,084,361	7
Rep.of Korea	9,728,650	11,824,737	12,151,868	13,143,063	11
Other countries	39,087,927	44,836,786	41,810,427	53,250,429	12
Total Export	**165,862,501**	**191,067,154**	**192,839,140**	**222,148,023**	**11**
Top Importers					
Japan	34,376,118	39,804,916	45,492,771	46,674,207	11
The US	25,943,637	29,465,670	$29,417,653	32,111,612	8
Germany	16,118,253	18,612,689	$12,170,677	13,672,044	-2
Spain	$8,842,250	6,952,649	6,892,205	11,786,433	16
France	8,842,250	8,932,952	9,921,831	11,786,433	10
Thailand	8,146,505	7,922,882	9,263,463	10,118,916	8
Other countries	67,043,690	87,770,120	82,953,241	104,124,305	17
Total Import	**160,470,453**	**192,509,229**	**189,219,636**	**218,487,517**	**11**

Source: United Nations commodity trade statistics database (2014)

Unlike carrageenan export performance, the export volume of agar from Indonesia declined by 13% from 2010 to 2013. Many factors collectively influence the export volume of agar; therefore agar is mostly consumed and distributed in Indonesia. However, Indonesia has also been part of the group of global exporters during this period. Since 2010, Indonesia imported agar mainly from China and Malaysia. The import value of agar was similar to the export performance which decreased by 16% (Figure 2-11).

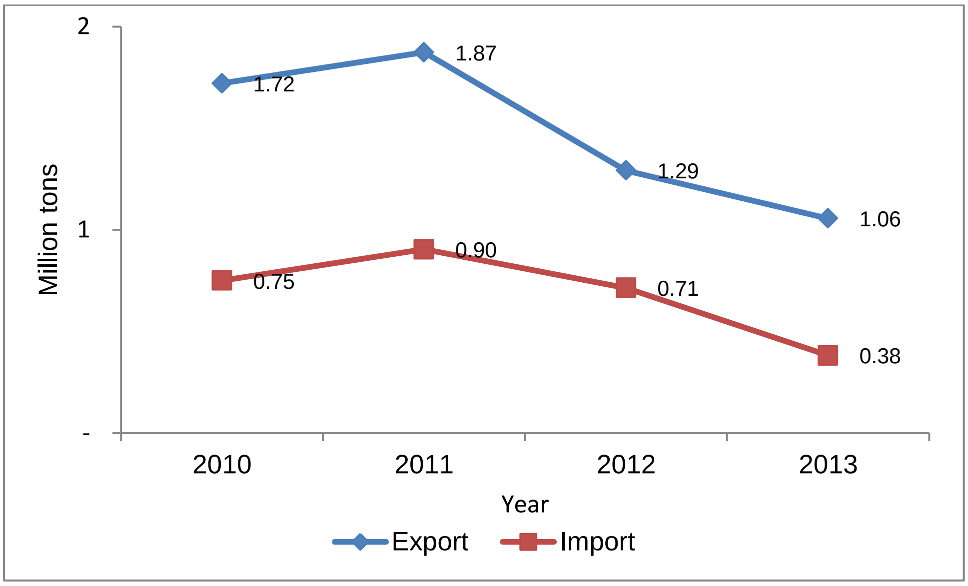


Figure 2-11: The volume of export and import of Indonesia's agar from 2010 to 2013
(United Nations commodity trade statistics database, 2014)

3 Seaweed Supply Chains in Indonesia

Supply chain management (SCM) concerns with integration of network organizations consisting of suppliers, manufactures, logistic providers, wholesalers/distributors, and retailers. The SCM aims are collaborating and managing the flow of products, services, finance, and information from suppliers to customers to achieve customer satisfaction, profitability, added value, and to create both efficiency and effectiveness. In the long term, the benefit of SCM is to achieve a competitive advantage within a system (Chopra & Meindl, 2013; Corominas, 2013; Lambert et al., 1998; Mentzer et al., 2008; Stock et al., 2010). While there are various definitions of SCM, they all have several common factors: collaboration with supplier and customers, flow activities, and balancing of supply and demand. A supply chain combines the concept of supplier relationship management (SRM) and customer relationship management (CRM) including customer service management, demand management, order fulfillment, manufacturing, flow management, product development, and commercialization and returns management (Mentzer et al., 2008).

An agri-food supply chain is a network system leading from the farm to the markets, which then carries agricultural products and services to the final consumers to satisfy consumer demands. The agri-food supply chain can be divided into three categories: the supply chain of perishable goods, non-perishable goods, and processed food products. Perishable products are fresh products with a limited shelf-life and variability in supply and demand such as fruits, vegetables and flowers. Non-perishable products are the products which can be stored for longer periods such as coffee, grains, and nuts (Ahumada & Villalobos, 2009; Aramyan et al., 2006). Processed food products contain agricultural materials and other materials that aid in processing the food by physical and chemical means. These products can be readily consumed by consumers such as canned food products, dairy products, chips, etc.

An important aspect in SCM is the identification of supply chain members which can be further distinguished as primary and supporting members. The primary members of a supply chain are all companies that conduct operational and/or managerial activities that are directly related to producing a specific product for a certain customer or market. The supporting members are companies that support resources, knowledge, utilities or assets for the primary members of the supply chain; they are not directly involved in the main production process of transforming raw materials into a product (Lambert et al., 1998)

The primary members of a seaweed supply chain in Indonesia having vertical collaboration can be distinguished as seaweed farmers, local collectors; large traders or exporters, and seaweed manufactures. Seaweed farmers, local collectors, and large traders are grouped into seaweed suppliers. In this case study, the focal company is one which processes raw dried seaweed into carrageenan or agar. Seuring & Müller (2008) define focal companies as companies that usually manage the supply chain, directly provide contact with customers, and manage the products or services offered. Upstream in the seaweed supply chain are seedling suppliers, seaweed farmers, local collectors, and large traders who supply raw dried seaweed to seaweed manufacturers, as well as carrageenan and agar companies. Downstream are transportation companies, retailers, exporters and blended producers of food hydrocolloids.

The primary members are supported by seedling suppliers, banking and/or financial institutions, cooperatives, and transportation services. National governments, universities, the Indonesian Scientific Institute (LIPI), and other institutions also support influential members of the seaweed supply chain, such as providing market and technical information. The governmental departments that primarily support the sector are the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, the Ministry of Trade, the Ministry of Cooperative and Small Medium Enterprises, and the State Ministry for Accelerated Development of Disadvantaged Regions. Other associations serve seaweed farmers, large traders and/or exporters and seaweed manufacturers. Three associations that are responsible for supporting primary members are the Indonesian Seaweed Association or *Asosiasi Rumput Laut Indonesia* (ARLI), the Indonesian Seaweed Farmers and Industries Association or *Asosiasi Petani dan Pengusaha Rumput Laut Indonesia* (ASPPERLI), as well as the Indonesian Seaweed Industry Association or *Asosiasi Industri Rumput Laut Indonesia* (ASTRULI). The general structure of Indonesia's seaweed supply chain is presented in Figure 3-1.

The significant processes of the seaweed supply chain can be grouped into the main and secondary areas. There are seven aspects of the main area: seaweed cultivation, seaweed maintenance, harvesting, drying, storage, distribution, and transforming raw dried seaweed into carrageenan or agar by-products. The secondary area is comprised of services, raw materials and supporting materials for cultivation and production of carrageenan and agar, by-products and coordination with authorities. Table 3-1 further describes the main and secondary areas of a seaweed supply chain.

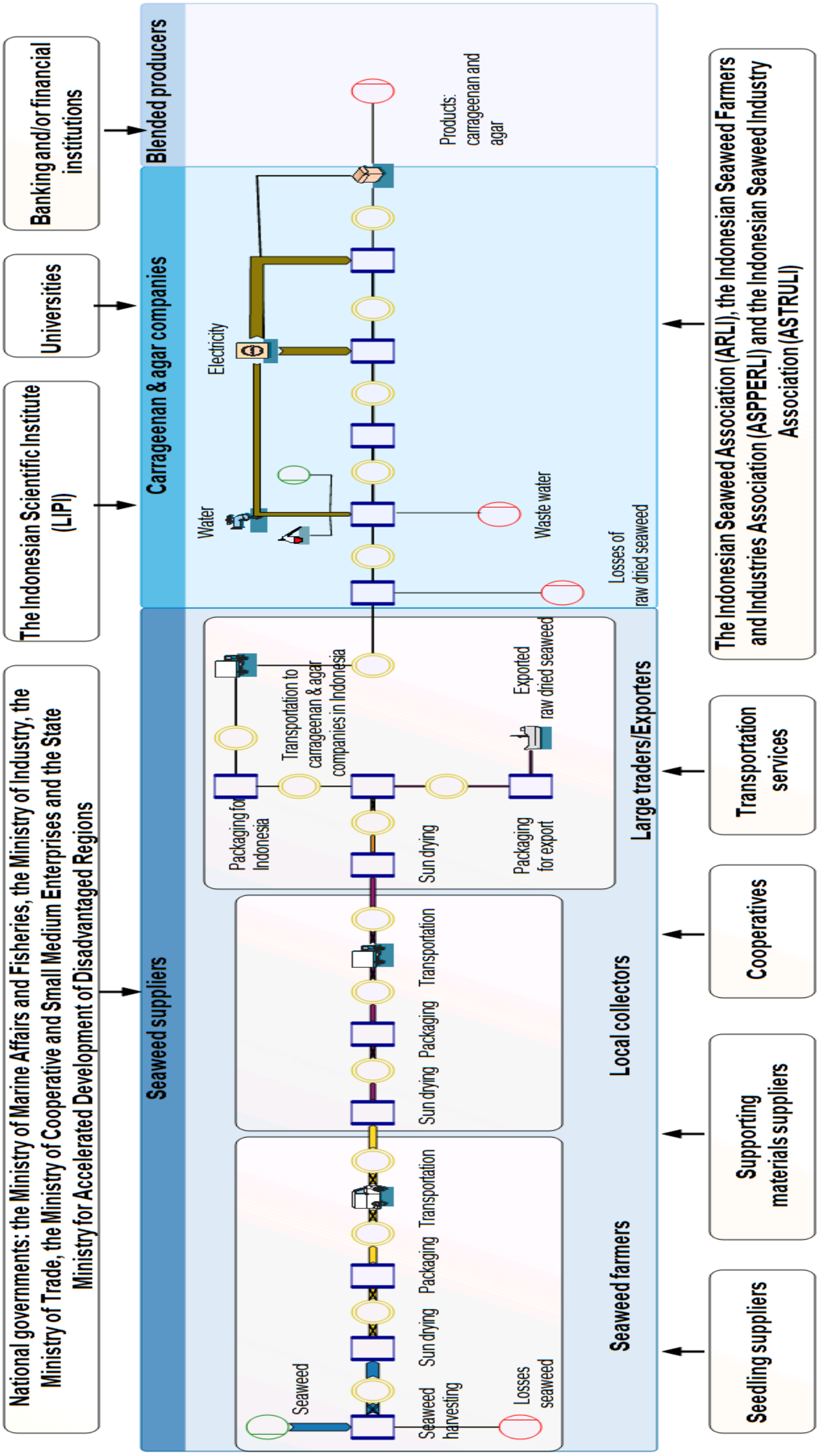


Figure 3-1: General structure of seaweed supply chains in Indonesia

Table 3-1: The main and secondary areas of a seaweed supply chain

No	Area	Actor	Explanation/Activities	Product
A	**Main area**			
1	Cultivation	Seaweed farmers	The goal of this step is to cultivate seaweed in a coastal marine for *E.cottonii* and in a pond for *Gracilaria.*	Seaweed
2	Seaweed maintenance		Maintenance of seaweed cultivation includes checking the main rope to determine it has any defects caused by high waves, or looking for sludge attached to the seaweed.	Wet seaweed
3	Harvesting		The harvesting process covers the cutting of mature seaweed after 6-8 weeks and removing ropes and foreign materials.	Wet seaweed
4	Drying	Seaweed farmers, middlemen/ local traders, large traders or exporters, carrageenan and agar companies	The process for reducing moisture content of seaweed as required (30-35%) is usually conducted by the product being placed in direct sunlight from three to four days. Additional foreign materials such as stone, salts and rope are also removed.	Raw dried seaweed (RDS)
5	Storage		Inventory of raw dried seaweed and products (carrageenan and agar) are collected and stored in a warehouse.	• RDS • Carrageenan: ATC, SRC, and RC • Agar
6	Processing	Carrageenan and agar companies	Raw dried seaweed is converted to carragenan or agar and is then packaged as ingredients for food industries such as dairy products.	• Carrageenan: ATC, SRC, and RC • Agar
B.	**Secondary area**			
1	Services	Non-government organizations, cooperatives, local traders, large traders, shipping companies, financial institutions	Consultation and monitoring for Good Agricultural Practices (GAP) of seaweed and Good Manufacturing Process (GMP) of carrageenan and agar manufacturers; quality improvement, financial support for supply chain members and transportation of both carrageenan and agar forms from large traders/exporters in Indonesia and abroad.	Consultation, logistics, trade, transportation, certification, loan
2	Raw materials and consumables	Large traders, shops, importers of supporting materials	These materials are essential sources for the production of carrageenan and agar. They are needed for adding product value.	• Cultivation materials: Seedlings, ropes, bottles • Production materials: RDS, chemicals substances, packaging
3	By-products	Carrageenan and agar companies	These are the by-products of the raw material which are then produced in order to be used often in other value chains.	Solid and liquid waste of seaweed for bio-fertilizer
4	Authorities	The MMAF, the Ministry of Industry, the Ministry of Trade, the Ministry of SMEs, the State Ministry for Accelerated Development of Disadvantaged Regions the State Ministry for the environment	Controlling and monitoring of legal provision, officially recognized as the audit of specific industries: Hazard Analysis and Critical Control Points (HACCP), Halal, management quality, environmental impact (solid and liquid waste).	• ISO 9000: • ISO 14000 • Halal certificate

Adapted from Schütz et al. (2014)

In general, the material flow from upstream beginning with seaweed farmers to large traders involves relatively similar activities consisting of sun drying, packaging, and transportation. These activities are clustered as the supply activities. Every functional aspect on the upstream side has decisions that need to be made. There are five major functional areas of seaweed supply including cultivation, harvest, drying, storage, and distribution. Cultivation decisions are made based on the allocation or share of the sea area, time for sowing seedlings, and required resources for growing the plant. Some of the decisions during harvesting include the right time for harvesting, transporting equipment and labor. Decisions related to drying cover drying method and required equipment for reducing seaweed moisture content. The concerns associated with storage include selecting a warehouse, inventory control, and the amount to stock. The main decisions required for distribution consist of transportation mode, route selection, and delivery schedule.

The material flow and energy analysis of focal companies producing carrageenan and agar differs by the steps of production and chemical materials. The analysis below is designed for describing the inputs and outputs of material and energy in a boundary system within the seaweed supply chain. It also allows us to calculate the requirements of raw materials and wastes of production systems. In this research, the Umberto NXT Universal 7.0. software also calculated the process models based on petri nets.

The Umberto software was developed by the Institute for Energy and Environmental Research Heidelberg Ltd. (IFEU) in collaboration with the Institute for Environmental Informatics Hamburg Ltd. (IFU) in 1990's. More than 100 users in worldwide networks ranging from industry members to researchers have been applied Umberto to their business or research.

The software can analyze energy efficiency and resource efficiency; Life Cycle Assessments (LCAs) and carbon foot printing; carbon management and sustainability management and environmental information systems both in a production plant and in a supply chain. Umberto provides to visualize material and energy flow systems with a Graphical User Interface (GUI). It also helps for identifying possibilities to enhance the system to reach economic and environmental goals (Brunner & Rechberger, 2004). The products of Umberto can be divided into four categories: Umberto NXT LCAs, Umberto NXT CO_2, Umberto NXT efficiency and Umberto NXT universal. For more detailed information of the software, is available at the Umberto web site (http://www.umberto.de/en/).

The flow of seaweed supply chain starting from the seaweed farmers to the large traders will be further described in Section 3.1. In Section 3.2, the flow of carrageenan consisting Alkali-treated *cottonii* (ATC), semi-refined carrageenan (SRC), and refined carrageenan (RC) as well as agar process will be explained in greater detail.

3.1 Supply of Seaweed

The supply of seaweed involves seaweed farmers, local traders, and large traders/exporters that have relative identical activities. Their activities consist of sun drying, packaging, and transporting of seaweed by farmers and traders.

3.1.1 Seaweed Farmers

Seaweed farming has significant consequences for economic improvement, environmental preservation, and social welfare particularly in coastal communities in Indonesia. From an economic perspective, seaweed farming is a major source of household income for families along coastal areas. The majority of these farmers are marginalized fishermen whose incomes are below the national poverty line[6]. Research shows that there is a significant relationship between seaweed farming and economic livelihood in Indonesia (Pollnac et al., 2001; Sievanen et al., 2005).

It is worth noting that seaweed farming does not significantly contribute to global warming. This view is supported by Matthews (1996) who writes that proposals of seaweed cultivation were frequently offered for reducing global warming in the climate engineering proposals. A number of studies have found that seaweed has a great potential as a CO_2 sink and for biomass production. Unlike other cultivations, seaweed farming does not require fertilizer, forest clearing, and heavy usage of fuel-burning machinery. It also does not compete with other terrestrial plants. Seaweed is a photosynthetic plant absorbing CO_2 through photosynthesis and producing a new source of biomass by taking up nitrogen, phosphorus and other valuable minerals. Seaweed has a rapid rate of photosynthesis because its cultivation only takes 45 days, which means that it absorbs carbon dioxide from the atmosphere more rapidly than other plants. Several studies on marine macro algae for carbon fixation have been conducted from technical, economic, and environmental aspects in small-scale operation (Chung et al., 2013; Chung et al., 2011, Gao & McKinley, 1994, Muraoka, 2004).

In terms of its social impact, seaweed farming provides many work opportunities for local people, both men and women. Seaweed cultivation is typically run as a family operation, with all of the adults of the household helping out. Land preparation, planting, maintaining and harvesting are generally done by men, while women typically make ropes, bind seedlings and dry the seaweed. Seaweed farming is most often conducted in a community based cluster (15-20 families), where each family manages an area of approximately 0.005-0.01 km^2. Most of the farmers use the long line method which has an average of 5.8 km. For 1 km of line can produce approximately 1.1 tons wet seaweed which is equal to roughly 10.9 tons per 0.01 km^2 (Neish, 2013). They not only cultivate seaweed but they also capture artisanal fish in the sea which further enhances their income.

The most important input in seaweed cultivation is the seedlings that are taken from the best plants selected from the previous harvest. Small-scale farmers who have a sufficient

[6] The national poverty line of Indonesia is IDR 200,262 per month or Euro 20 per month (World Bank, 2012)

amount of seedlings may sell their surplus to other farmers who will then use the seeds for three to five years. When a farm is affected by natural calamities, such as large waves, floods, or plant disease, the demand for seedlings are high. Limited access to seedlings can be a critical constraint to expanding seaweed production. In response to this, the Ministry of Marine Affairs and Fisheries has taken an initiative to solve the limited availability of seedlings. Other inputs that are necessary for seaweed cultivation are bamboo, stakes, nylon ropes, and ties. The materials are typically supplied by local retailers either in the community, in cities, or in larger towns.

Before seaweed is harvested, farmers check their plots 2-4 times a week in order to maintain yield quality. The following activities are proper maintenance concerns in order to achieve successful seaweed cultivation: removing invasive animals or plants, removing and replacing infested seaweed such as *ice-ice* in *E. cottonii* type before it has a chance to damage the remaining seaweed, sludge removal, replacing broken ropes, and strengthening anchors. Water exchange is conducted at least once a week for seaweed that is cultivated in a pond.

Seaweed is manually harvested after 45 days, or 6 to 8 weeks. Manual harvesting involves the removal of the main ropes containing seaweed, bringing seaweed onto the boat, transporting seaweed to land, and cleaning away other unwanted materials. Farmers typically use canoes for harvesting seaweed, especially for the *E. cottonii* type.

Farmers usually harvest the seaweed in the morning for two hours so that it can be immediately placed in the sun to dry and to minimize loss. Directly after harvesting, the farmers wash away any foreign materials that may be attached to the seaweed such as sand, sludge, and shells. Finally, wet seaweed is laid out under the sun in a drying area surrounding the farmer's house.

Drying is the most important post-harvest activity in seaweed production. Many households along the shore have their own drying pads made of slit bamboo, while some use communal drying pads or shared drying facilities. Drying facilities are not only used for seaweed, but also for drying other land crops such as rice, maize, and coconuts. The majority of Indonesian seaweed farmers are able to dry their seaweed under the sun year-round.

Freshly harvested seaweed needs to be sun dried for three to four days, depending on weather conditions, in order to reach the proper moisture content. The moisture content is approximately 40-50% for *E. cottonii* and *E. spinosum,* and 30-40% for *Gracilaria*. It is important to note, however, that the moisture content is measured subjectively through directly feeling the seaweed, without any specific tools or tests.

The hanging method is generally the best method for drying seaweed. With this method, the seaweed is hung about 2 meters high in a bamboo building that helps keep away contaminants and allows for faster drying. Seaweed should not be exposed to freshwater during the drying process. A common problem with the drying process is that seaweed is occasionally set out to dry in the sand or on the pavement in some areas. It leads to a higher moisture content and a greater number of contaminates by foreign matter such as sand and stones.

After seaweed is dried, it is cleaned and then packed into 50 kg woven bags. Afterwards, farmers bring the product to a local collector either by a pickup car with a maximum capacity of 2 tons or a wagon in remote areas. In some cases, the local collector may pick up the semi-raw dried seaweed. The distance between farmers and the local collector averages approximately 30-60 km.

There are two types of seaweed farmers: independent farmers and dependent farmers. Independent farmers have the flexibility to sell their seaweed to a local trader or wherever else they may want to sell it. The seaweed is usually sold based on the price offered by a local trader. Dependent farmers, on the other hand, have to sell their seaweed exclusively to a specific local trader with whom they have made an informal agreement, often based around opportunities which provide financial support to the farmers.

Seaweed farmers frequently operate in accordance with informal and formal groups, such as cooperatives that also act as seaweed collectors. For example, Agroniaga cooperatives, well known as *Celebes*, were founded in 2004 and already have around 5,000 members spread out in South Sulawesi Province covering sub-province Palopo, Luwu, North Luwu, East Luwu, Bone, Sinjai, Wajo, and Central Sulawesi Province in Morowali.

The activities of a cooperative include financial and non-financial activities. Cooperatives are often able to provide financial support to farmers for seaweed cultivation. Non-financial support from the cooperative may consist of post-harvest activities such as drying, packaging, selling the seaweed to agar companies, and consulting about seaweed quality. For instance, *Celebes* has a large warehouse, packing house and hydraulic press machine which are all useful during product preparation. *Celebes* also has an approximately 0.07 km^2 seaweed cultivation field laboratory that can be used for comparing seaweed quality.

Financial resources for seaweed farmers may come from local collectors, families or relatives, national government initiatives such as the Ministry of Marine Affairs and Fisheries, the Ministry of Cooperative and SMEs, non-governmental organizations (NGOs), and international donor institutions such as the International Finance Corporation (IFC) World Bank, Deutsche *Gesellschaft für Internationalle Zusammenarbeit* (GIZ), Asian Development Bank (ADB), and the Swisscontact Foundation. Despite having access to financial support from the government and other organizations, many farmers prefer to borrow money from local collectors or relatives/friends; this is due to faster processing times as well as the thought that assistance from government and organizations projects are not sustainable long-term solutions.

Farmers especially in remote areas do not have access to information on price and raw dried seaweed quality requirements. Generally, seaweed farmers do not know the price of the market or the utility of seaweed in industry. In 2004, the International Finance Corporation Program for Eastern Indonesia Small and Medium Enterprise Assistance

(IFC PENSA) World Bank launched a seaweed development program called Seaplant.net. This program assists seaweed farmers in their cultivation, harvesting, post-harvesting, marketing information, and encouraged the development of farmer cooperatives and local seaweed processing facilities. The program focused on five provinces: South Sulawesi, North Sulawesi, Tenggara Sulawesi, Bali, and West Nusa Tenggara. Three years later, the program was continuing as community empowerments in coastal farmers. The goal of the program was capability building of seaweed farmers for adding value of seaweed especially in *E. cottonii* and *E. spinosum*.

IFC Pensa has been made an internet networking platforms which farmers and buyers can access the information on price and sources of raw dried seaweed through the internet (www.jasuda.net). The project team gave a tutorial on how to use the internet to the farmers. Local collectors or large traders provide the price information to the Jasuda team. Furthermore, seaweed farmers, local collectors, and large traders make a community through Jasuda as a way to exchange information in market.

3.1.2 Local Collectors

Local collectors, or middlemen, are often established in villages, districts and sub-districts surrounding seaweed farmers. Local collectors can be representatives of agar or carrageenan manufactures, independent organizations, or cooperatives formed by seaweed farmers. A local collector is usually a head of seaweed farmer groups and typically operates in groups of 50 to 100 farmers. The majority of local collectors from seaweed famer groups can be found in Bali and South Sulawesi. The local collector's job is to help the farmers sell their seaweed to large traders who will eventually sell it to carrageenan and agar companies.

Approximately 60-70% of seaweed farmers have binding relationships with local collectors or exporters. The relationship between seaweed farmers and local traders is usually very strong and with a high level of trust. Bonds of personal trust and commitment are key to the success of a relationship between a farmer and a local collector as reported by Neish (2013).

Local traders play an essential role in the financial support of the farmers, as well as being critical for technical information and market access. Access to formal financial services for seaweed famers is limited. Therefore, pre-financing from local traders has commonly been a traditional source of production credit for farmers to purchase seedlings, ropes, nylon strings, and other supplies. This financial support is usually in the form of an informal agreement, where local traders pay the farmers in advance of their seaweed production. The farmer then has access to the money without any other form of collateral agreement. The financial assistance is beneficial not only for seaweed cultivation, but also to cover day-to-day family expenses or urgent situations such as illness.

Local traders also educate farmers on proper seaweed cultivation, as well as new techniques and methods so that a higher production quality can be achieved. They are a primary factor in ensuring the quality and yield of seaweed. Occasionally, large traders cooperate with local government to conduct the program before farmers cultivate seaweed. Educating and training to farmers on proper seaweed cultivation methods is a critical job for local traders and cooperatives in order to achieve a high quality product.

Local traders are also responsible for providing market information such as price and requirements expected from large traders or manufacturers. Local traders often exchange information in the seaweed industry through informal discussions with farmers.

A local collector purchases seaweed from seaweed farmers in the form of semi-raw dried seaweed. However, the quality often does not meet local collectors' requirements such as high moisture content (> 35%). There is also the occasional problem of increased weight caused by excess salt in the seaweed bale. While local collectors occasionally offer incentive prices for a product with reduced moisture content, they usually end up re-drying the seaweed they receive from farmers in an attempt to meet the required moisture content of exporters or large traders. This is a primary reason why local collectors buy dried seaweed from farmers at a lower price and, furthermore, local traders have price authority, called a price-taker, when buying raw dried seaweed from farmers.

Local traders collect the raw dried seaweed in a warehouse where the initial cleaning of foreign matters, sorting and removing of ties and drying of seaweed to the required moisture content takes place. The seaweed is dried in three to four days under the sun for an average of 32-35% water content for *E. cottonii* and 20-25% moisture content for *Gracilaria*.

After large quantities of seaweed are collected from many farmers, it is then transported and sold to large traders and/or exporters by truck. Local collectors sell and deliver raw dried seaweed to large traders which are typically located in major port cities or the province capital.

3.1.3 Large Traders

Large traders usually operate with 3 to 10 people and have 20 members from local trader groups. Most large traders act as exporters and are spread out across Surabaya, East Java and Makassar, South Sulawesi. Large traders and/or exporters are located in the capital of the province, or sub-province, where they have a large warehouse to store the dried seaweed.

Large traders can be divided into two categories: independent traders and dependent traders. An independent trader sells dried seaweed to any carrageen and/or agar producers. A dependent trader, however, works to represent producers through formal contracts which require them to sell their seaweed to pre-determined manufacturing firms. The majority of large traders are independent traders who freely select to whom they sell seaweed.

The relationship between local and large traders is generally quite strong, as the two parties regularly discuss the availability, quality and price of seaweed. Large traders are also able to lend financial support to local traders through advanced financing so that they can buy the seaweed from the farmers. A strong relationship between a local trader and a large trader can determine the difficulty of level entering the seaweed supply chain as a new large trader. It is typically difficult for a new large trader to make agreements and contracts right after they have been established because local traders are often not willing to trust them until a relationship has been built.

Large traders clean, dry, and transport raw dried seaweed directly to agar and carrageenan producers in Indonesia and abroad. Large traders/exporters distribute 25% raw dried seaweed of *E. cottonii* for carrageenan manufacturing in Indonesia and 75% for export, for example, to China and Europe. Only 20% of *Gracilaria* is exported and the rest (80%) is used as raw materials for agar companies in Indonesia.

A large trader receives an average of 75 tons per day of raw dried seaweed from local collectors. After collection, the seaweed is dried for 24 hours to reach about 30-32% water content for *E. cottonii*, with less than 5% foreign matter or impurities. The drying area is 550 m^2 with an approximate capacity of 5 ton The weight ratio of wet seaweed of *E. cottonii* and its raw dried seaweed ranges between 6:1 and 8:1 on average, while the ratio of wet *Gracilaria* and its raw dried seaweed is about 10:1.

The requirements of raw dried seaweed are clean, moisture content below 35%, and "trading games" do not occur, e.g. adding water and foreign materials to increase the weight of the product (Neish, 2013). Raw dried seaweed should meet the national standard requirements as described in Table 3-2**.**

Table 3-2: National standards for raw dried seaweed of Eucheuma and Gracilaria

Type of test	**Unit**	**Standard requirement**	
		Eucheuma	***Gracilaria***
Sensory	1 – 9	7	7
Chemistry			
• Moisture content	% fraction period	30–35	15–18
• Clean anhydrous weed	% fraction period	Minimum 30	Minimum 30
Physics			
Foreign matter	% fraction period	Maximum 5	Maximum 5

Sources: Nurdjana et al. (2009)

After the drying process, it is important that the products be kept in a dry condition, while avoiding things such as sand and other foreign materials. A large trader will usually have a warehouse, anywhere from about 850 m^2 with an 800 ton capacity to store the raw dried seaweed. The dried seaweed is stored in a warehouse for no longer than one week. Afterwards, large traders deliver the raw dried seaweed to agar or carrageenan manufacturers both in Indonesia and overseas using 20 or 40 feet containers. For the most part, raw dried seaweed is individually packaged in compressed bales that are roughly 100 kg in weight.

Transportation costs, especially for type of *E. cottonii* from a large trader to a carrageenan manufacturer, for example from South Sulawesi to West Java or East Java, are more higher than the costs of exporting to abroad destinations such as to China.

Product delivery from Sulawesi to China is conducted as regular shipping with large container ships. On the other hand, deliveries of products between islands in Indonesia are transported by a small ship and the frequency is rare. Lack of an integrated port affects the reliability of commercial product deliveries in Indonesia. A mismatch between national and local regulatory practices in the transportation sector influences inland transportation cost. For example, local governments frequently raise costs by issuing permits, charges and licenses. Costs of illegal and legal charges during transport also significantly affect transportation costs in Indonesia.

Raw dried seaweed from large traders to seaweed manufactures is distributed by land and sea. A large trader will use land transportation for distribution to the same island, while using sea transportation for different domestic islands and overseas. The lead time of an order is approximately 14 days, from the time the manufacturer places an order until arrival, for products to reach another island or even locations abroad.

Local and large traders play an important role in the seaweed supply chain. The long supply chain, especially from the farmers to large trader players, reduces the profit margin of seaweed farmers and increases the lead time for focal companies. Having many tiers of traders decreases the overall benefit for seaweed farmers. For example, farmers sell raw dried seaweed at €0.50 per kg while large traders sell the same product at €1.20 to focal companies.

The price of *E. cottonii* is higher than that of *Spinosum* and *Gracilaria* varieties because its price is highly influenced by the world price. This is a major driving force behind many farmers' preference to cultivate *E. cottonii* seaweed. The price for the *E. cottonii* variety, for both wet and dried seaweed in the domestic market is shown in Table 3-3.

Table 3-3: Price of seaweed in the domestic market in 2013

Species	**Farmer [€/kg]**		**Local trader [€/kg]**	**Exporter [€/kg]***
	Wet seaweed	**Dried seaweed**	**Dried seaweed**	**Dried seaweed**
E. cottonii	0.39	0.79 – 0.94	0.79 – 1.14	0.86 – 1.26
E. spinosum	0.24	0.24 – 0.32	0.35 – 0.39	0.43 – 0.51
Gracilaria	0.10	0.31 – 0.60	0.43 – 0.62	0.47 – 0.78

Source: Field research in 2013

**Currency converter by Oanda.com on 30 April 2013*

3.2 Seaweed Manufacturing in Indonesia

Carrageenan and agar manufacturers have been steadily growing in Indonesia due to family business. Strategic decisions in this business are mostly influenced by owners and directors who have family bonding. Many of these firms are nationally based, and some are operate with affiliate companies located across the globe; this is unlike the situation in the Philippines, where the majority of hydrocolloid companies are large multinational firms such as Shemberg Corporation, Cargill, and CP Kelco (Panlibuton et al, 2007). In the Indonesian market, more than 60% of the companies are carrageenan processing companies that are producing alkali-treated *cottonii* (ATC), semi-refined carrageenan

(SRC), and refined carrageenan, the remaining 40% are agar companies. Carrageenan and agar are classified as medium and large industries, while traditional food companies are generally categorized as small and micro industries.

For over a decade, seaweed processing has been relatively widespread, mainly through simple methods and technology, in an effort to process it as raw materials for cake, pudding and agar. During the 1940s, the Indonesian government supported efforts to build agar companies through research projects. During this initial research, all species of commercial seaweed was collected in order to analyze the essential contents of seaweed for industrial purposes, especially in the US and Europe (Soegiarto & Sulustijo, 1990).

In 1930, the first large-scale agar company was built in Kudus, Central Java. However, the factory was closed during World War II. After the war, only small agar companies remained, primarily in Jakarta, Surabaya and Bandung in Java Island, and Padang in Sumatra Island. The average capacity of an agar manufacturer was 7-8 tons per year, which required 70-80 tons of raw materials annually in 1975. Higher public demand and government support influenced the emergence of these factories after World War II (Soegiarto & Sulustijo, 1990).

Seaweed industrialization in Indonesia initially started in 1976 when PT Bantimurung Indah was founded and began producing ATC in Makassar, South Sulawesi. In 1988, PT Galic Artabahari was launched as an SRC company in Bekasi, West Java. The first agar producer in Indonesia was PT Surya Indo Algae which was built in 1990 in Surabaya, East Java.

Currently, there are 26 companies in the hydrocolloids industry in Indonesia that are categorized as medium and large companies. The majority of these 26 companies are located in East Java, West Java, and South Sulawesi, while traditional food companies widely operate in Bali and West Nusa Tenggara (Figure 3-2). They generally produce only one or two products such as semi-refined carrageenan and alkali-treated *cottonii*. However, it is also possible for them to produce many other products such as the firm, Java Biocolloid, which produces agar, carrageenan, and blended stabilizer products.

It is an ideal business scenario when carrageenan and agar manufacturers are located close to seaweed cultivation areas, for example, in South Sulawesi. However, some of the carrageenan and agar firms chosen Java to build their plants in East Java or West Java due to better infrastructure, i.e. to be near the harbor with easy access to supporting materials necessary for production. An increase in the lead time for agar and carrageenan companies is typically caused by long-distance relationships between seaweed farmers and focal companies. Most seaweed farmers are located in the eastern part of Indonesia, for example in Sulawesi Island (South Sulawesi, Southeast Sulawesi, Central Sulawesi, and Gorontalo). Most agar and carrageenan firms, however, are located on Java Island primarily in West Java and East Java. The distance between seaweed famers in Makassar (South Sulawesi) to agar companies in Bogor (West Java), for example, is approximately 1,408 km or 875 miles, requiring two to three days by ship.

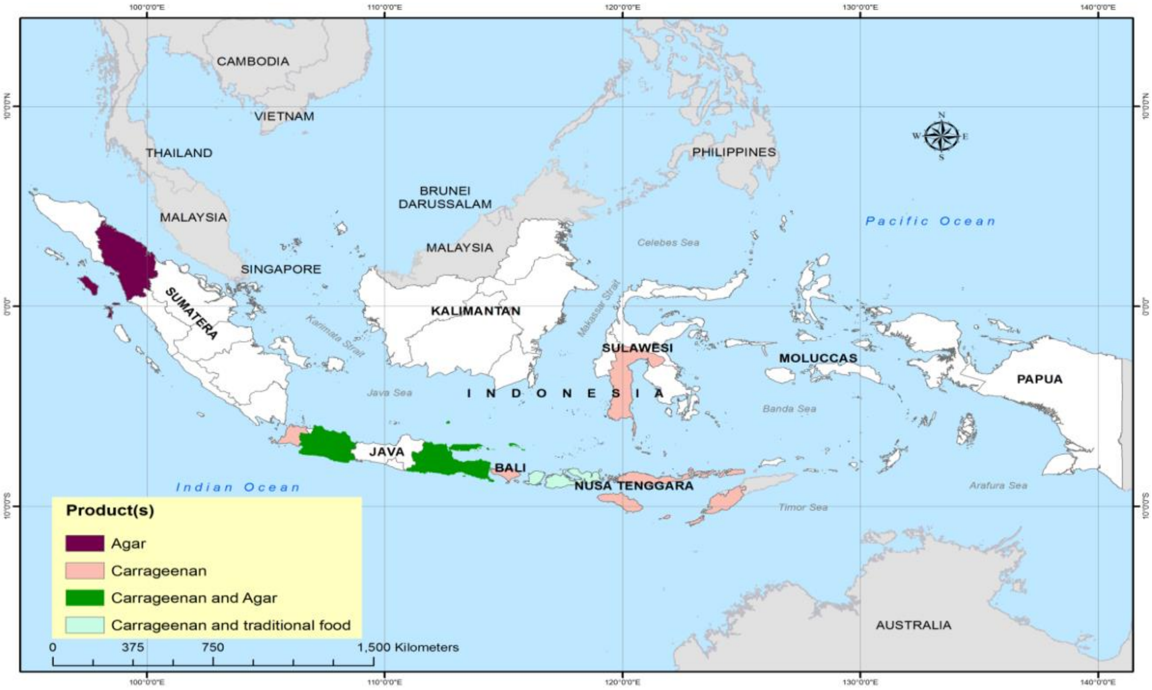


Figure 3-2: Location of carrageenan, agar, and traditional food companies in Indonesia

Refined carrageenan is extracted carrageenan which has now been almost entirely replaced by semi-refined carrageenan. Thus, semi-refined carrageenan is more widely used for industrial purposes than refined carrageenan due to better product development and technology (Panlibuton et al., 2007; Cybercolloids, 2012). In Indonesia, only a few companies produce refined carrageenan (15%) because it requires a much higher investment than semi-refined carrageenan production. Capacity and location of carrageenan and agar companies in Indonesia is described in Table 3-4.

Table 3-4: Capacity and location of carrageenan and agar companies in Indonesia

No.	Company	Capacity [tons/year]	Location	
			Province	Sub Province
A. Carrageenan companies				
A.1. Alkali-tretated companies				
1.	PT Madura Prima Interna	720	East Java	Sumenep
2.	PT Indonusa Algaemas Prima	1,200		Malang
3.	PT Langit Laut Biru	180	East Nusa Tenggara	Maumere
4.	PT Algae Sumba Timur	2,160		Waingapu
5.	PT Saraswati	120	Central Sulawesi	Luwuk,Banggai
Average capacity of ATC		876		
A.2. Semi-refined carrageenan				
1.	PT Gumindo Perkasa Industri	1,200	Banten	Cilegon
2.	PT Hydrocolloid Indonesia	1,200	West Java	Bogor
3.	PT Indo Seaweed	1,560	East Java	Mojokerto
4.	PT Amarta Carragenan	480		Pasuruan
Average capacity of		1,110		
A.3. ATC (30%) dan SRC (70%)				
1.	PT Galic Arthabahari	2,040	West Java	Bekasi
2.	PT Bantimurung Indah	1,000	South Sulawesi	Maros
3.	PT Cahaya Cemerlang	720		Makassar
4.	PT Giwang Citra Laut	960		
5.	PT Wahyu Putra Bima Sakti	1,200		
Average capacity of ATC		476		
Average capacity of SRC		1,108		
A.4. Refined carrageenan				
1.	PT Centram Pasuruan	432	East Java	Pasuruan
2	PT Hakiki Donarta	1,200		
3.	PT Algalindo Perdana	1,000		
Average capacity of RC		877		
Total carrageenan companies 17 companies				
B. Agar companies				
1.	PT Agarindo Bogatama	3,000	Banten	Tangerang,
2.	PT Agar Swallow	480	West Java	Bogor
3.	PT Surya Indo Algas	240	East Java	Sidoarjo
4.	PT Satelit Sriti	480		Surabaya,
5.	PT Agar Sehat Makmur Lestari	360		Pasuruan
6.	CV Agar Sari Jaya	240		Malang
7.	PT Indoking Aneka Agar	360	North Sumatera	Medan
	Average capacity of agar	737		
RC and agar company				
1.	PT Java Biocolloid	RC: 1,440 Agar: 800	East Java	Pasuruan
Traditional food company				
1.	PT Phoenix Mas	240	West Nusa Tenggara	Mataram
Total carrageenan and agar companies 26 companies				

Source: Ministry of Marine Affairs and Fisheries (2012)

The total production of carrageenan in 2010 (9,080 tons) is higher than agar powder production (2,820 tons). The average annual growth of carrageenan production was 11% but was only 2% for agar production from 2006 to 2010 (Figure 3-3). This is primarily influenced by the greater global demand for carrageenan than agar. Most carrageenan (80%) is used as raw materials for international food ingredients in China, Europe and the US. Agar powder, however, is mostly absorbed by the domestic market (80%) as a food source in 2011. The utilization of carrageenan and agar in foreign and domestic markets is shown in Table 3-5.

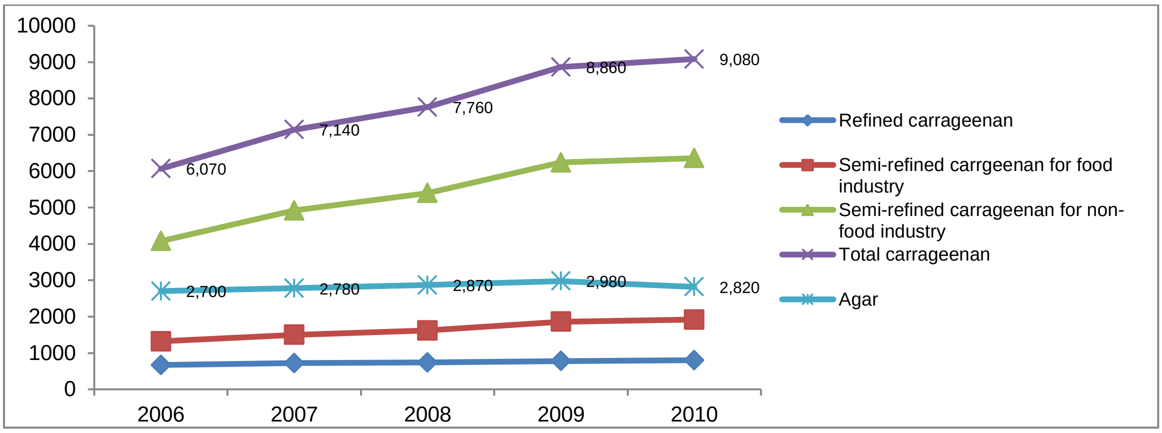


Figure 3-3: Production of carrageenan and agar 2006-2010 in Indonesia (tons)
Source: Anggadiredja et al. (2011)

Table 3-5: Utilization of carrageenan and agar in domestic and foreign market

Year / Type	Domestic market	Foreign market
2009		
Carrageenophytes	36,070 (23.3%)	118,990 (76.7%)
Agarophytes	28,600 (81.6%)	6,450 (18.4%)
2010		
Carrageenophytes	33,815 (24.2%)	106,205 (75.8%)
Agarophytes	24,805 (80.8%)	5,895 tons (19.2%)

Source: Anggadiredja et al. (2011)

The following sections explain the processes of carrageenan: alkali-treated *cottonii* (ATC), semi-refined carrageenan (SRC), and refined carrageenan (RC); and agar manufacturing. The type of ATC and SRC discussed in this paper is kappa carrageenan for which the raw material is *E. cottonii.*

The input and output of ATC, SRC, RC and agar use the software Umberto NXT Universal 7.0.with a basis of 1 kg carrageenan and 1 kg agar. Each material flow system consists of processes and flows. A process contains detailed instructions of what happens to its input and output flows.

Information on the ATC and SRC processes was obtained from an Indonesian carrageenan company, PT. Bantimurung Indah, in South Sulawesi. The production process of RC is based primarily on information by Oktavia (2012) because most RC companies did not provide detailed information on the process. Detailed information of agar commercial production is not accessible because agar processors do not generally release details regarding their production process. Therefore, the information of agar production is explored through desk studies.

3.2.1 Carrageenan Manufacturing

As described in Chapter 2, carrageenan is a linear polysaccharide with a high molecular weight, and is comprised of repeating galactose units and 3, 6-anhydro-D-galactose, both sulphated and non-sulphated, joined by alternating α-(1, 3) and beta β-(1, 4) glycosidic links. These carbohydrates have the ability to form gels in aqueous substances. The color of carrageenan can range from off-white to snowy or tan to yellowish, yet is free of odor and taste. The gel is heat-reversible, i.e. it can dissolve after being heated up and the solution can form a gel while cooling.

The carrageenan production process begins with the identification of quality including moisture content and a certain amount of foreign matter such as sand and stones. Quality personnel conduct random checks the raw dried seaweed in baled seaweed. The inspection process of dried seaweed is very important because it directly affects the quality of end-products (Stanley, 1987).

There are three types of carrageenan products: alkali-treated *cottonii* (ATC), semi-refined carrageenan (SRC), and refined carrageenan (RC). ATC is the simplest production of carrageenan in the forms chips, or simply called *cottonii* chips. SRC is dried alkali-treated *cottonii* chips which can be milled at a variety of particle sizes such as 40-60 mm depending on the needs of the customer, and is then sold as a powder. SRC or processed *Eucheuma* seaweed (PES) is produced by using the hot alkali method and refined carrageenan is made by using the alcohol precipitation or gel pressing method. SRC and RC are sold in powder form in either a white or beige color. Unlike refined carrageenan (RC), semi-refined carrageenan (SRC) contains residual cellulose and has a cloudy color. The cellulose in refined carrageenan is removed through a filtration process. SRC is widely used in the dairy and meat industries where clarity is not a requirement.

RC and SRC are listed in ANNEX 1 of the European Parliament and Council Directive 95/2/EC on Food Additives. RC and SRC are separately labeled in the European Union. RC is assigned as E407 and SRC as E407a. However, according to the FDA, there is no distinction between RC and SRC labeling; thus, both are labeled as ‘carrageenan’ on food products in the US.

3.2.1.1 Production of Alkali-Treated *Cottonii* (ATC)

The production of Alkali Treated *Cottonii* (ATC) involves pre-treatment, alkali treatment, neutralization; chopping, sun drying, and packaging (Figure 3-4). The ATC processor receives dried and baled seaweed from local or large traders. The firms can then store the dried seaweed for up to three months. First, pre-treatment is conducted to remove foreign matter from the dried seaweed. The actual carrageenan process begins with the selection and washing of the raw dried seaweed (RDS). The RDS may contain impurities which must be manually removed because it will greatly affect the quality and strength of the carrageenan gel.

The purpose of the alkali treatment is to maintain proper levels of potassium hydroxide 8.5% and a pH value of 13. The alkali treatment is furthermore intended to improve homogeneity and to stimulate the reaction process. The raw dried seaweed is extracted with a hot alkali solution in a tank using potassium hydroxide for *E*. *cottonii* at pH 13 for two or three hours at 80–85^{0}C, while occasionally being stirred. This temperature is required for catalyzing the formation of galactose. If the temperature is below 80°C, the dried seaweed cannot dissolve and kappa conversion does not occur. The alkali solution supports the swelling and maceration of the seaweed, while the hydroxide helps to reduce the number of sulfates in the carrageenan and generates 3, 6-andhydro-D-Galactose, therefore increasing the gel strength of carrageenan (Stanley, 1987; McHugh, 2003; Imeson, 2009).

Next, the seaweed is neutralized by soaking in fresh water to extract the residual alkali (Stanley, 1987). Neutralization is then carried out for 24 hours in order to reduce sodium chloride levels. In the following stage, the neutralized seaweed is chopped to a size of 2-4 cm and is then dried under the sun for one or two days. In some instances, a drying machine is used with a temperature of 60-70^{0} C. Chopping is done before drying in order to increase drying efficiency. The input and output of 1 kg ATC is shown in Table 3-6.

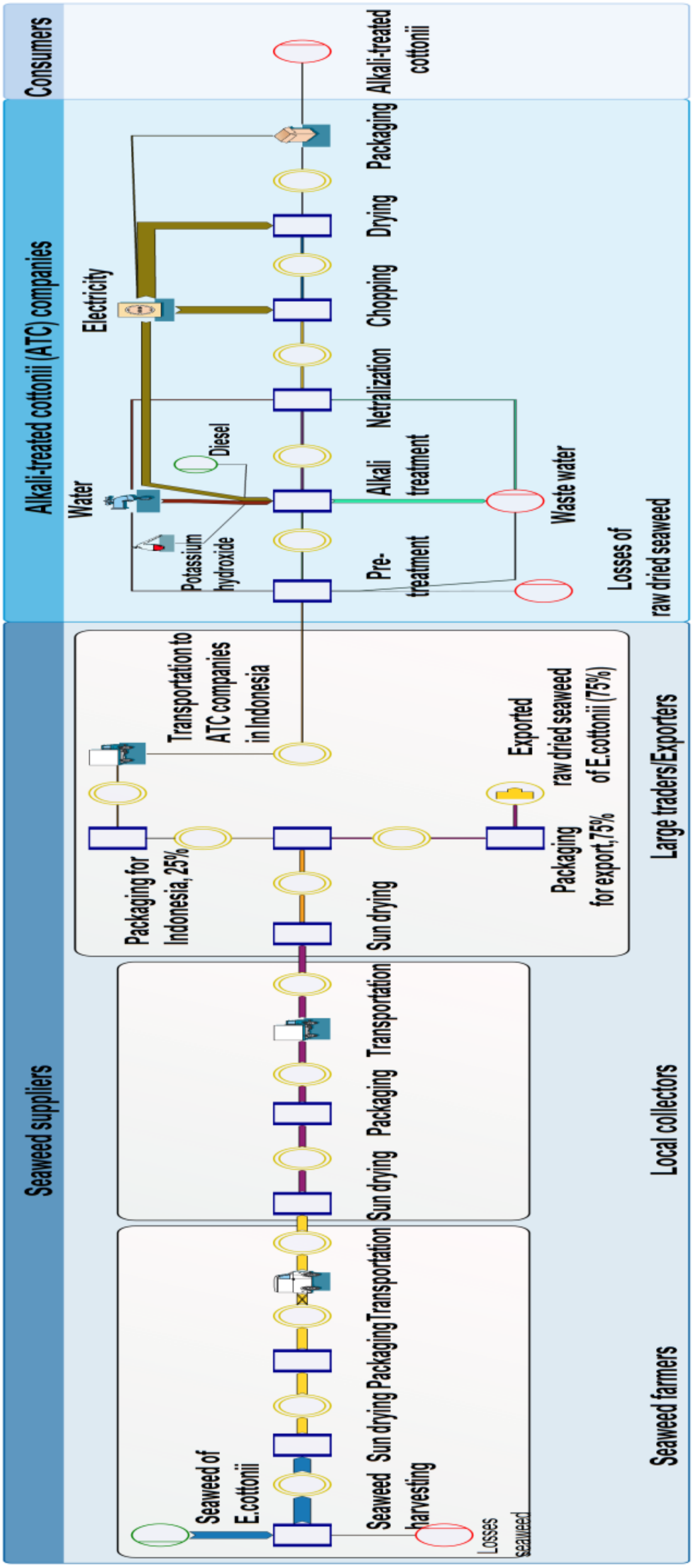


Figure 3-4: The alkali-treated cottonii supply chain

Table 3- 6: Input and output of ATC production

Input/ Output	Material	Quantity	Unit	Process
Input	Diesel	0.34	kg	Alkali treatment
	Electricity, medium voltage	1.48*	MJ	Multiple processes: drying, packaging, chopping, and alkali treatment
		0.90	MJ	Multiple processes: alkali treatment, packaging, and chopping
	Potassium hydroxide	0.20	kg	Alkali treatment
	Water, well, in ground [natural resource/in water]	0.05	m^3	Multiple processes: netralization, alkali treatment, and pre-treatment
	Wet seaweed of *E.cottonii*	32.47	kg	Seaweed harvesting
Output	Losses of raw dried seaweed	0.11	kg	Pre-treatment
	Lossess wet seaweed of *E.cottonii*	1.62	kg	Seaweed harvesting
	Packaged ATC	1.00	kg	Packaging
	Wastewater, average	0.05	m^3	Multiple processes: netralization, alkali treatment,and pre- treatment

*Dried using oven drying

3.2.1.2 Production of Semi-Refined Carrageenan (SRC)

The primary goal of semi-refined carrageenan (SRC) production is to increase the gel properties in seaweed. Of importance are the galactose units in carrageenan which are sulfated in the 6-position before they transform to 3, 6-anhydro galactose in the SRC process. The galactose position improves the gel and further strengthens characteristics of the carrageenan.

It is preferable to chop the raw dried seaweed into lengths of approximately 5-8 inches before it is treated with the alkali solution, a process which helps to increase the seaweed's surface area. After the chips are milled, they are dried under the sun or with a drying machine. Machine drying is mostly used to avoid microbial contamination, especially for food grade purposes.

The production of SRC involves pre-treatment, alkali treatment, neutralization, chopping, drying, and milling. Pre-treatment is conducted to remove foreign matters from the dried seaweed. The process begins with the selection and washing of raw dried seaweed. It is important that the foreign matter is removed and the product is sufficiently washed before the extraction process because it will influence the quality of the gel strength.

Afterwards, the cleaned and sorted raw dried seaweed is extracted in hot alkali solution using potassium hydroxide for E. c*ottonii* and sodium hydroxide for *Spinosum* for two hours to reach 12% potassium hydroxide or three hours for 8% potassium hydroxide at approximately 80–85^{0}C while stirring occasionally. The potassium hydroxide solution has a pH in a range of 12-14. The optimum condition of the alkali treatment is to use potassium hydroxide at a pH level of 13 for 1 hour at 80^0 C (Normah & Nazarifah, 2003). If the temperature is below 80^{0}C, raw dried seaweed cannot dissolve and kappa conversion does not happen. The alkali solution then helps with the swelling and maceration of the seaweed. The hydroxide aids in reducing the number of sulfate in the carrageenan and generates 3, 6-andhydro-D-Galactose, therefore increasing the gel strength of the carrageenan (Stanley, 1987; McHugh, 2003; Imeson, 2009)

Next, the seaweed is neutralized in the same ways as alkali-treated *cottonii* (ATC) by soaking in fresh water to extract the residual alkali (Stanley, 1987). In the following stage, the neutralized seaweed is chopped to a size of 2-4 cm. The seaweed is chopped and milled to improve mixing and the overall gel quality for end-products. Afterwards, the chopped seaweed is dried under the sun for one to two days: It is also possible to use a drying machine at 60-70^{0}C for about six hours to achieve the standard moisture content of 14% of SRC. Machine drying is mostly used to avoid microbial contamination, especially for food grade purposes. There are three optimal conditions for drying: drying at 70^{0}C for 5 hours, 60^{0}C for 8 hours, or 50^{0}C for 24 hours (Normah & Nazarifah, 2003). Finally, SRC is packaged and sealed using 25 kg of weight low-density polyethylene film materials. The final product can be stored for at least two years after the production date.

Table 3-5 shows the input for producing 1 kg SRC and Figure 3-5 describes the SRC supply chain.

Table 3-7: Input and output of SRC production

Input/ Output	Material	Quantity	Unit	Process
Input	Diesel	0.35	kg	Alkali treatment
	Electricity, medium voltage	16.20	MJ	Multiple processes: drying, milling, alkali treatment, packaging, and chopping
		15.61	MJ	Multiple processes: alkali treatment, packaging, chopping, and milling
	Potassium hydroxide	0.20	kg	Alkali treatment
	Water, well, in ground [natural resource/in water]	0.05	m^3	Multiple processes: netralization, alkali treatment, and pre-treatment
	Wet seaweed of *E.cottonii*	33.13	kg	Seaweed harvesting
Output	Losses of raw dried seaweed	0.11	kg	Pre-treatment
	Losses of SRC	0.02	kg	Milling
	Lossess wet seaweed of *E.cottonii*	1.66	kg	Seaweed harvesting
	Packaged semi-refined carrageenan	1.00	kg	Packaging
	Wastewater, average	0.05	m^3	Multiple processes: netralization, alkali treatment, and pre-treatment

*the SRC powder is dried using oven drying

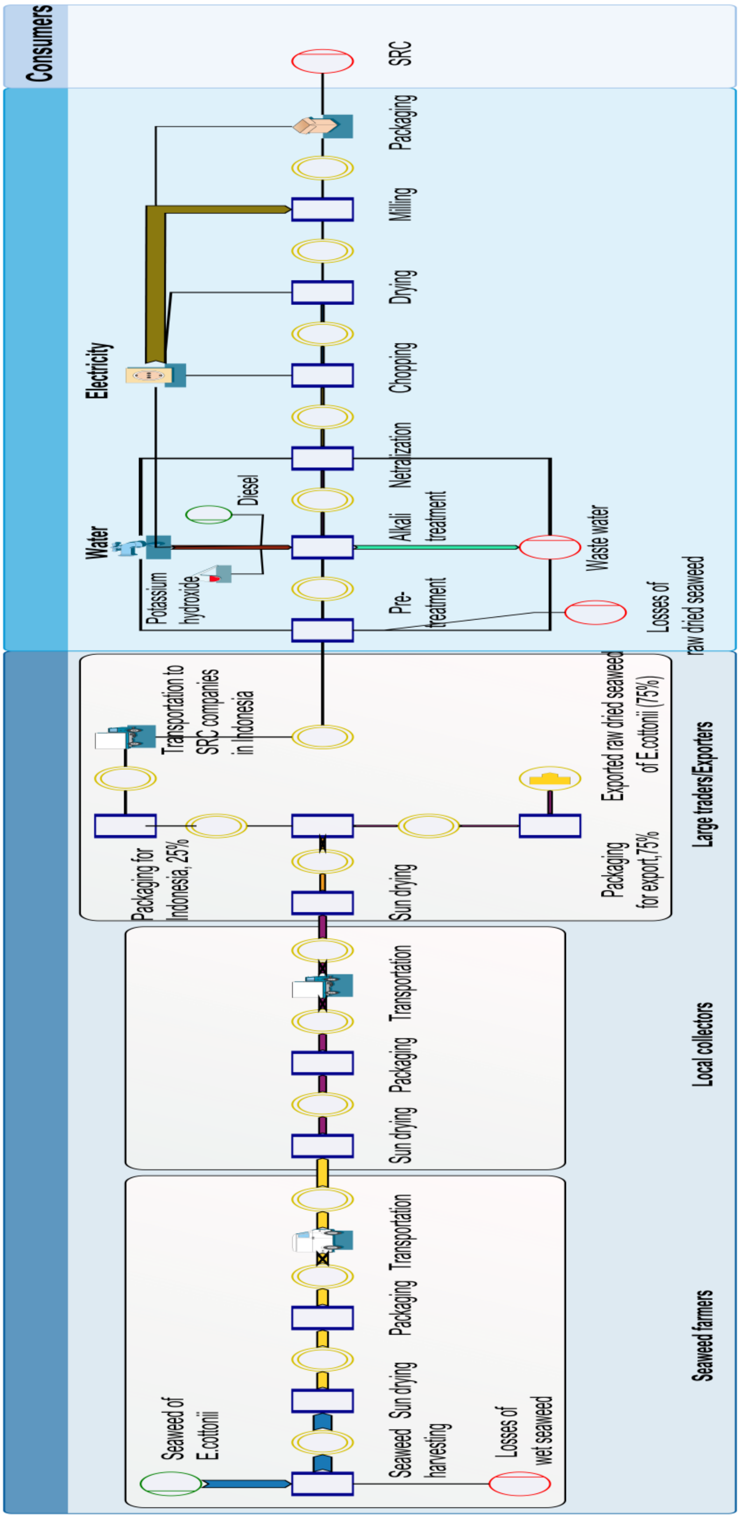


Figure 3-5: The semi-refined carrageenan supply chain

The SRC production process takes roughly 4 hours with an average production of 13.3 tons. A company receives an average of 60 tons of raw dried seaweed per delivery from large traders. Chemical materials used in the process, such as potassium hydroxide, are imported from Korea or Taiwan at an average of 20 tons for each delivery with a lead time of 30 days. Other supporting materials, such as packaging materials, are bought from the shops located in larger cities of the province such as Makassar, Jakarta, and Surabaya. The companies frequently ship ATC and SRC to China, South Korea, Europe, and the US, delivering an average of 20 tons each time, with a lead time of 2 to 7 days from order to delivery.

3.2.1.3 Production of Refined Carrageenan (RC)

There are two methods for extracting and refining carrageenan: the alcohol precipitation method and the gel press method, both of which are intended to extract carrageenan and transform it into a solid product. The alcohol precipitation method can be used for all types of carrageenan production, while the gel press method can only produce kappa carrageenan. The gel press method originated in agar processing and has been widely used in the processing in the Asian jellies (CyberColloids, 2012).

Most carrageenan companies use the pressing method due to its lower production costs. Usage of the alcohol precipitation method has been decreasing over recent years due to high production costs. With this method, additional costs are necessary for the installation of a non-flammable tool, alcohol purifying distillation equipment, large quantities of alcohol and the cost of alcohol removal (CyberColloids Ltd., 2012; Imeson, 2009; Panlibuton et al., 2007).

In the alcohol precipitation method, isopropanol is added to the filtrate until carrageenan is precipitated as a fibrous coagulum[7]. Afterwards, the coagulated carrageenan is pressed in order to remove the solution. It is then washed with more alcohol to further dehydrate it. The product is then dried using a drying machine at 70^{0}C for 15-20 hours. Next, the dried carrageenan is milled to an appropriate size which may range from 80 to 270 mesh[8]. Before the carrageenan can be blended with other materials, it is tested for composition and functional qualities such as moisture, viscosity, and gel strength. Finally, the refined carrageenan is packed and stored in a warehouse. The alcohol solution must be removed both from the liquids and the dryer to ensure quality, it is then recycled (McHugh, 2003).

In this paper, however, the gel press method is chosen for quantifying the production of refined carrageenan. The first step of the gel press method is similar to SRC production. To begin with, the seaweed is washed in running water to remove sand, salts and other foreign matter. Then, the washed seaweed is heated with water containing alkali reagent such as sodium hydroxide or potassium hydroxide. Alkali is used to reduce sulfate from the molecules and increase the 3, 6-Anhydro-D-Gluctose. After the alkali treatment,

[7] Coagulum is a coagulated mass or substance (www.meriamwebster.com)

[8] Mesh is powder particle size by passing the powder through a specific sized screen. The larger the mesh numbers the smaller particle size of the powder. Based on the standard, 200 mesh is equal to 74 µm and 400 mesh is equal to 37µm

seaweed that does not dissolve is removed by a coarse filtration or centrifugation system, the solution is then filtered again in high temperatures. Following this step, the solution contains 1-2% carrageenan that is usually concentrated to 2-3% by vacuum distillation and ultrafiltration.

After the carrageenan solution is filtrated, it is streamed through fine holes into potassium chloride solution to form a gel. Water in the gel is removed through two methods: the freeze-thaw method and the gel press method. In the freeze-thaw method, the gel is collected and washed with more potassium chloride to remove excess water. The gel is then frozen and thawed to further assist in excess water removal.

The gel pressing method can be done by forcing water out of the gel with the use of pressure equipment. After it is squeezed for several hours, the sheets of gel are chopped and dried in a hot air dryer. The dried carrageenan is then milled to an appropriate size according to buyer specifications. Before the carrageenan powder is packaged and stored, it is blended with various materials to meet the varying requirements of buyers.

The results of the SRC and RC products described above are in a pure form and sold as primary ingredients, though they are generally blended with other hydrocolloids and ingredients. Afterwards, before these products are used in products such as dextrose salts or other gums like locus bean gum to make carrageenan more cohesive, or Xanthan gum to make carrageenan softer.

Some blended producers do not manufacture carrageenan, but procure RC or SRC powder from external suppliers for use in their products. Two of the largest blending companies in the world are Ingredient Solutions International and Eurogum (Panlibuton et al., 2007). Some of their final products are meat blended carrageenan with xanthan gum, starch, LBG and salts. Other products include water gel blended carrageenan with locus bean gum and konjac, while many dairy products are often blended with locus bean gum and starch. Final end-products for these blended products include meat (carrageenan blended with xanthan gum, starch, locus bean gum, and salts), water gel (carrageenan blended with locus bean gum and konjac), and dairy products (carrageenan blended with locus bean gum and starch). The RC supply chain is shown in Figure 3-6 and the input and output for 1 kg production of RC is described in Table 3-8.

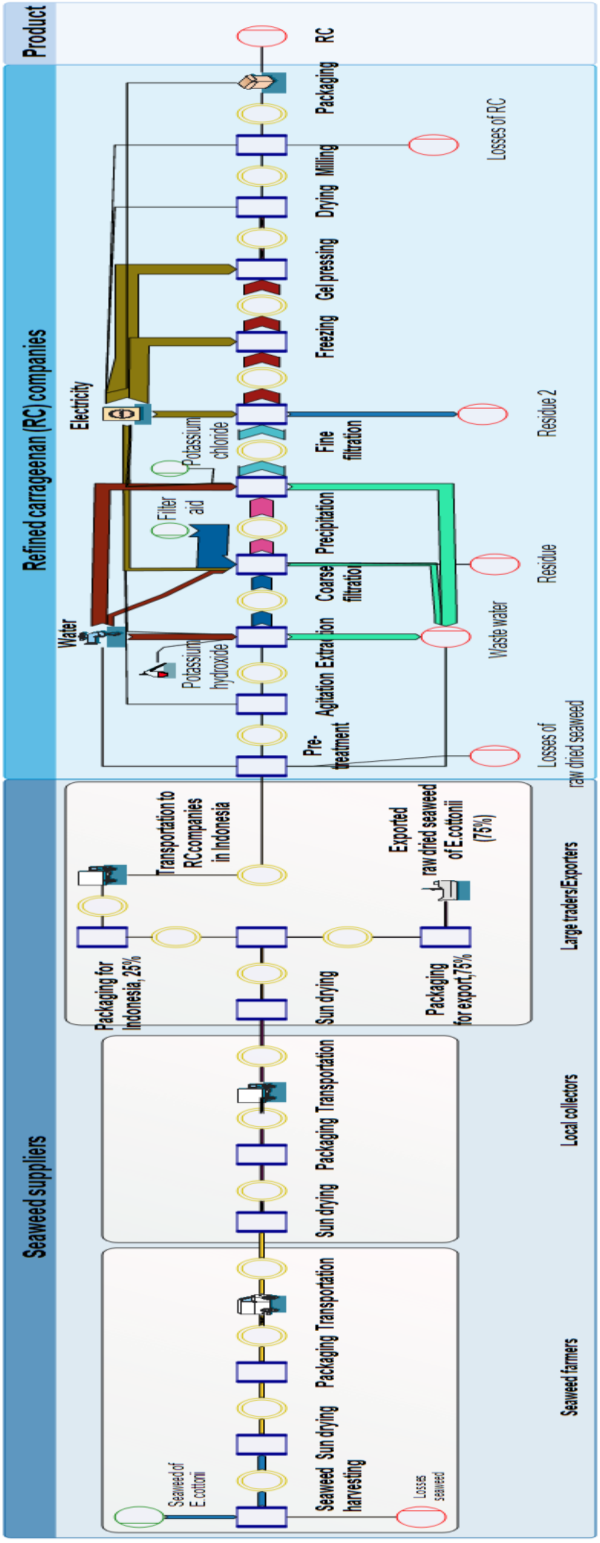


Figure 3-6: The refined carrageenan supply chain

Table 3-8: Input and output of RC production

Input/ Output	Material	Quantity	Unit	Process
Input	Electricity, medium voltage	173.69	MJ	Multiple processes: extraction, packaging, gel pressing, freezing, fine filtration, precipitation, coarse filtration, agitation, drying, and milling
	Filter aid	169.90	kg	Coarse filtration
	Potassium chloride, as K_2O	1.33	kg	Precipitation
	Potassium hydroxide	0.28	kg	Extraction
	Water, well, in ground [natural resource/in water]	0.31	m^3	Multiple processes: coarse filtration, extraction, pre-treatment, and precipitation
	Wet seaweed of *E.cottonii*	45.97	kg	Seaweed harvesting
Output	Losses of raw dried seaweed	0.15	kg	Pre- treatment
	Losses of RC	0.02	kg	Milling
	Lossess wet seaweed of *E.cottonii*	2.30	kg	Seaweed harvesting
	Packaged RC	1.00	kg	Packaging
	Residue	5.66	kg	Coarse filtration
	Residue 2	60.96	kg	Fine filtration
	Wastewater, average	0.31	m^3	Multiple processes: pre-treatment, extraction, precipitation, coarse filtration

3.2.2 Agar Manufacturing

An agar company should pay special attention to produce good quality products and to optimize production costs. In order to build an efficient agar plant, the following things are needed: access to dried seaweed, freshwater availability, up-to-date technology, and a controlled laboratory. An agar manufacturer needs large quantities of freshwater for the production process and waste disposal (McHugh, 2003). The petri net of agar supply chain is shown in Figure 3-7.

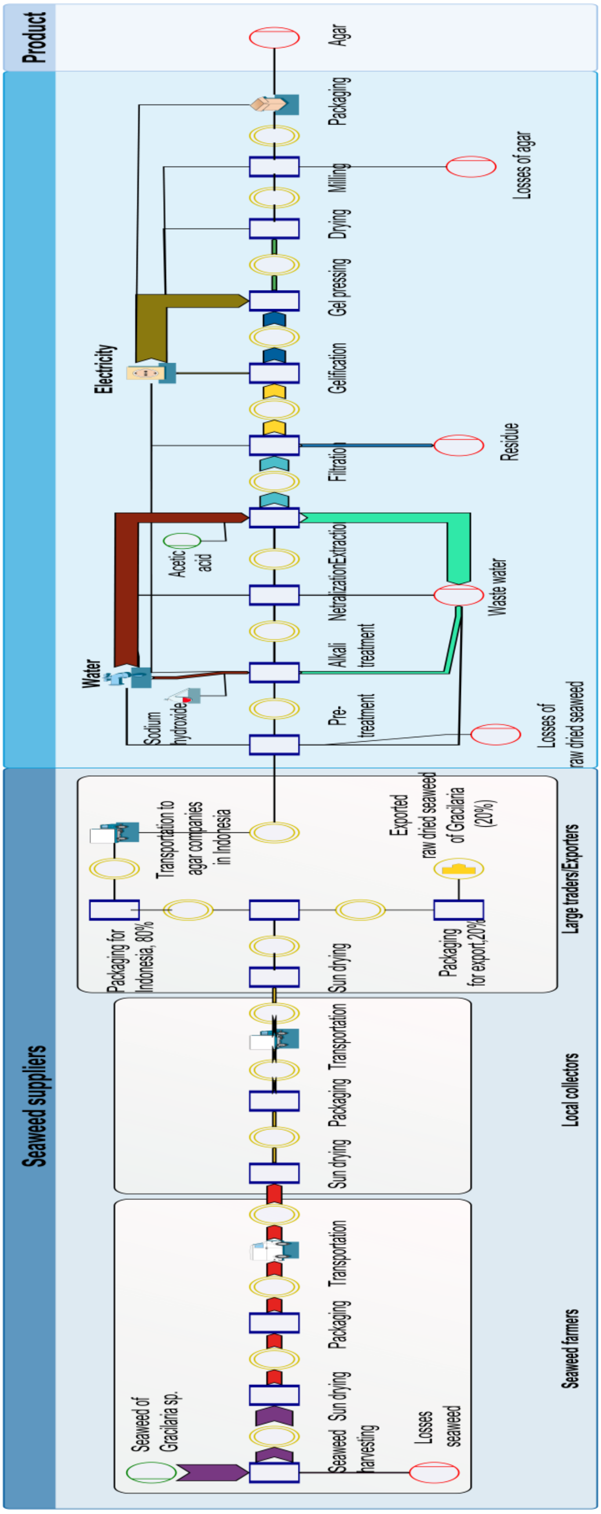


Figure 3-7: The agar supply chain

Good production facilities and high quality raw materials are primarily requirements for high quality products. It is necessary to establish hygienic practices in and out of the laboratory. As the laboratory is essential to control for the quality of the product, as well as continually improving research and development, stainless steel equipment is used to guarantee hygienic standards. Most companies have a clearly defined operational standard procedure in their production system. Seaweed waste resulting from the filtration process is often used for growing several types of edible mushrooms, plant tissue culture media or as an organic fertilizer.

Agar can be produced through various methods, but the most basic method includes extracting agar from seaweed with hot water, separating the agar from its residues by filtration, and isolating the agar from solution. Agar can be made traditionally and industrially. The traditional process conducted by simple tools has end-products in strip and block forms. However, industrial agar is sold in powder form and is produced with the use of modern technology. The industrialized agar production process is similar to the refined carrageenan method that uses either the freeze-thaw method or the gel press method. Most agar companies use the gel press method because the production costs are lower than with the freeze-thaw method.

First, during pre-treatment, the raw dried seaweed is soaked in water and is washed to remove sand, stones, nylon strings, and other impurities. Here, depending on which seaweed variety is used, differences in treatments are present. *Gelidium* is simply washed with freshwater and is then put into a hot-water tank. In contrast, *Gracilaria* must be treated with an alkali solution after it is washed to improve the gel strength, the washed seaweed is then heated in sodium hydroxide solvent (2-5%) at 85-90^{0}C for one hour to two hours. Alkali treatment improves the gel strength of agar because it transforms L-galactose 6-sulfate into 3, 6-anhydro-L-galactose. Before the seaweed is extracted and placed into hot water, the seaweed is washed with water or sometimes very weak acid to neutralize any residual alkali (McHugh, 2003) .

Acetic acid (CH_3COOH) is added into hot water for seaweed extraction until the solution reaches a pH of 6-6.4. *Gelidium* can be extracted under pressure at 105-110^{0}C for two to four hours, achieving higher yields in less time. *Gracilaria*, on the other hand, is treated at 95-100^{0}C for four to six hours. Next, the seaweed residue is filtered out with a coarse filtration system. During the filtration process, it is important to keep the product in hot temperatures (85-100^0 C) to avoid gel formation. The hot filtrate is then cooled, allowing a gel to form, although it can still contain up to 99% water. The gel can then be cut into pieces to extend its surface area allowing for easier removal of the water.

The water can be removed from the gel, either by the freeze-thaw or gel press methods. In the freeze-thaw method, the gel is frozen to form ice crystals and is then thawed allowing the water to drain away from the product. A bleaching dialysis is then conducted to reduce any coloring, after which the product is washed again to remove the bleach. The process of removing water can be done by gel press method where pressure equipment (hydraulic pressing) is used to release water from the gel.

After the water removal process, the product is dried in a hot-air dryer and is milled to a particular size, commonly 80-100 mesh. Before the agar powder is packaged, it is sometimes blended with other materials, flavoring for instance, in accordance with customer demand. An agar food grade product should have a moisture content of less than 18%, ash below 5%, gel strength above 750 g/cm^2, and a bacterial count below 10,000 bacteria per gram (Armisen & Stanley, 1987). Physical characteristics of agar include the color range of white shades to yellow, while being odorless. The input and output results to produce 1 kg agar calculated by the software Umberto is presented in Table 3-9.

Table 3-9: Input and output of agar production

Input/ Output	Material	Quantity	Unit	Process
Input	Acetic acid, without water, in 98% solution state	0.17	kg	Extraction
	Electricity, medium voltage	167.42	MJ	Multiple processes: gelification, packaging, gel pressing, drying, milling, extraction, filtration, and alkali treatment
	Sodium hydroxide	0.08	kg	Alkali treatment
	Water, well, in-ground [natural resource/in water]	0.09	m^3	Multiple processes: extraction, netralization, alkali treatment, and pre-treatment
	Wet seaweed of Gracilaria	89.62	kg	Seaweed harvesting
Output	Losses of agar	0.02	kg	Milling
	Losses of raw dried seaweed	0.04	kg	Pre-treatment
	Losses wet seaweed of Gracilaria	4.48	kg	Seaweed harvesting
	Packaged agar	1.00	kg	Packaging
	Residue of agar	15.24	kg	Filtration
	Wastewater, average	0.09	m^3	Multiple processes: netralization, extraction, alkali treatment, and pre-treatment

Overall, the main input of ATC, SRC, RC, and agar is briefly described in Table 3-10. Wet seaweed for agar production is the largest volume which it requires 89.62 kg for producing 1 kg agar. The production of RC requires the largest electricity and water. Producing 1 kg RC needs electricity 173.69 MJ and water 0.31 m^3. For the purpose of this paper, waste water is assumed to have the same value as the water requirements for all production systems.

Table 3-10: Comparison of the main input for producing 1 kg of ATC, SRC, RC and agar

Product	Wet seaweed (kg)	Electricity (MJ)		Water in ground (m^3)	Potassium hydroxide (kg)
		Oven drying	Sun drying		
ATC	32.47	1.48	0.90	0.05	0.20
SRC	33.13	16.20	15.61	0.05	0.20
RC	45.97	173.69	-	0.31	0.28
Agar	89.62	167.42	-	0.09	0.08

4 Identification and Assessment of Seaweed Supply Chain Risks

Risk identification and risk assessment are critical steps in risk management because they influence to the risk mitigation and risk monitoring. These critical processes are conducted as part of a series of steps in the managerial process. Many scholars have suggested that empirical studies connected with risk identification and their assessments are necessary in order to understand the complex system of supply chain risks. Practical studies can be used as a starting point for developing managerial guidelines and frameworks for supply chain risk management (Jüttner et al., 2003).

The chapter is organized as follows: Section 4.1 describes the overview of risk management, Section 4.2 provides theoretical reviews of supply chain risk management, Section 4.3 analyzes a practical implementation in order to identify and categorize the risks within the seaweed supply chain in Indonesia, and Section 4.4 describes the assessment of seaweed supply chain risks.

4.1 Overview of Risk Management

The concept of risk was initially established and associated with gambling theory in the seventeenth century, which had been introduced by the French mathematicians, Blaise Pascal and Pierre de Fermat (Frosdick, 1997). Afterwards, the term risk began being applied by the insurance industry in England in the 1830s (Moore, 1983) Systematic studies of risk began in the post-World War II time period with interest lying in the risk assessment of chemical or nuclear power plants (Renn, 1998). Risk management was further applied in business fields and in the education curricula of business in the 1950s and 1960s, as well as being relevant in the growth of technology and globalization (Grose, 1992; Snider, 1991).

The word ‘risk’ originally comes from the early Italian word *risicare*, which means to dare (Bernstein, 1996). The meaning of risk, however, has developed over time and has become a subject of discussion between social and natural science researchers (Frosdick, 1997). Growing studies of risk from the natural and social sciences reflect that risk is a discipline in the process of rapid development (Möller, 2012). The term risk may define both negative and positive impacts from an event. But, March and Zur Shapira (1987) have shown that positive impacts are assessed by most practical business as “chances”, and not as risks.

The definition and study of risk have been acknowledged in many business and management fields, especially in finance and insurance, strategic management, economics, and international business management (Manuj & Mentzer, 2008). Specifically, the definition of risk is the probability or likelihood of danger, damage, loss, injury, threat, hazard, and any other unwanted event which may or not may occur during a certain period of time (Hansson, 2004; Mitchell, 1995; Renn, 1998). Assessment of the probability of loss and the significance of the loss for an event *n* could be expressed in the following formula:

$$\text{Risk}_n = \text{Probability (loss}_n\text{)} \;\mathbf{.}\; \text{Business Impact (loss}_n\text{)} \qquad (1)$$

Many articles usually use the word risk in connection with the terms uncertainty and vulnerability. Uncertainty and risk can be established as anything that might happen in the future. Some researchers, however, distinguish between the terms risk and uncertainty in a different perspective. Risk has been defined as an event which is measurable, manageable and as having a probability of the outcomes being predicted. In contrast, uncertainty is not quantifiable and the probability of the outcomes is not known (Khan & Burnes, 2007; Waters, 2007). Uncertainty has been defined as the perceived inability to predict something accurately, or something that cannot be extended to include a probabilistic estimation of an event or a decision (Hansson, 2004; Manuj & Mentzer, 2008; Milliken, 1987).

On the other hand, other academics claimed that uncertainty, risk and vulnerability are correlated with one another. Miller (1992) mentioned that uncertainty arises when something “reduces the predictability of corporate performance, that is, increases risk”. Chapman et al. (2002) defined vulnerability as the exposure to serious disturbances arising from risks. Christopher and Peck (2004), however, defined vulnerability as an ‘exposure to serious disturbances arising from risks within supply chains as well as risks external to the supply chain’. Franck (2007) summarized that uncertainty can generate risk or become a key driver of risk, which leads to vulnerability.

Risk is inherent in human existence and is an essential part of human decision making from the simplest to the most complex decision (Chicken & Posner, 1998). In the area of business, increasingly more complex circumstances, dynamic situation, accelerated technological change, a fast-changing world are the factors affecting existence of risks and more production networks or supply chains. Risks are inherent and unavoidable in all supply chains since the supply chains will face an adverse event that would disturb normal flow of materials and goods. The risk issues are becoming one of the main focuses in the supply chain to compete in a market global (Craighead et al., 2007).

Therefore, risk should be managed in order to minimize the likelihood of negative effects resulting from an undesired event. It is not possible to completely eliminate risk, but the effects can be reduced by implementing risk management. A good risk management approach has proactive actions rather than reactive ones to control potential negative future events. Royal Society Study Group on Risk Assessment (1992, p.3) defines risk management as “the making of decisions concerning risks and their subsequent implementation, and flows from risk estimation and risk evaluation”.

According to White (1995), a good risk management approach deals with identification and mitigation of these risks by minimizing the likelihood of an event to give maximum sustainable value to all of the activities of the organization. Risk management includes the planning, organizing, implementing, and monitoring of activities intended to minimize risks to a tolerable level.

According to Degraeve (2004), understanding risks provides valuable knowledge and information that can increase our understanding of future events. Risk management helps with preparing for problems, improving current scenarios, reducing costs, comparing results and business continuity. Degraeve further emphasizes the importance of information, explanation, and the justification for a skilled decision maker. In addition, Sadgrove (2005) argued that risk management required to be embedded into the organization, and awareness of risk should be encouraged.

4.2 Supply Chain Risk Management

Supply chain management strives to improve the performance of the supply chain and to reach competitive advantages of its partners. However, a supply chain faces uncertain conditions which come from both internal and external forces, such as an increasing dynamic environment, coordination of many supply chain members, and handling long lead times. A number of studies have found that globalization, outsourcing, centralized distribution, centralized production, lean processes, reduction of inventory holding, reduction of supplier base, complex products and service, information technology-dependence and lack of information are all drivers of risk in supply chains (Harland et al., 2003; Jüttner, 2005; Pfohl et al., 2010). Natural and man-made disasters can also negatively influence the supply chain flow. These complex situations can lead to disturbances in the chain which restrict the overall performance of a supply chain. Increasing risk drivers in a supply chain should be well-managed to face the complexities and dynamic conditions. Therefore, risk management is becoming an essential part of a comprehensive supply chain management.

A supply chain requires specific and adequate responses, in terms of proper techniques, attitude, and strategies for managing risks. Smart decision-making and appropriate response time in the case of a disturbance, along with corrective actions can mitigate the effects of any disruptions in other elements of the supply chain.

Companies should be able to understand serious risks within a supply chain, but they often do not have appropriate responses to risky situations. Many companies are not familiar with supply chain risk management and they do not effectively calculate cost/benefit analysis or return on investment to develop risk minimizing programs (Sodhi & Tang, 2012).

4.2.1 Definition and Pillars of Supply Chain Risk Management

A precise definition of supply chain risk is found in only 18% of academic papers (Heckmann et al., 2015). There is, however, a consensus among scholars that risks within the supply chain can be described as disturbances in the flow of materials, information, products, and financial cash as outcomes deviate from original suppliers to the end-user, as well as the social and institutional network (Jüttner, 2005; Jüttner et al., 2003; Pfohl et al., 2010). This view is supported by Kersten et al. (2006) who state that supply chain risk is loss assessment of an adverse event by its probability within a company, its network and environment affecting the business process of at least one company in the supply chain.

The concept of supply chain risk management is a multidisciplinary field that combines at least three areas: supply chain management, risk management, and crisis management (Sodhi & Tang, 2012). Supply chain risk management is a strategic approach which connects to operational management (Jüttner et al., 2003; Lavastre, et al., 2012). According to Jüttner et al. (2003) and Jüttner (2005, p.124), supply chain risk management is 'the identification and management of risks for the supply chain, through a coordinated approach among supply chain members, to reduce supply chain vulnerability as a whole'. This definition is close to similar to Tang (2006, p.453) who defines supply chain risk management as 'the management of supply chain risks through coordination or collaboration among the supply chain partners so as to ensure profitability and continuity'.

This definition has been further extended to include strategies and technical methods which help to minimize supply chain risks. Kersten et al. (2006, p.8) defined supply chain risk management as 'a concept of a supply chain management, which contains all strategies and measures, all knowledge, all institutions, all process and all technologies, which can be used on the technical, personal and organizational level to reduce supply chain risks'. A supply chain can tackle and cope with the risks as long as they take into account two elements: supply chain risks (operational risks or disruption risks) and mitigation strategies based on supply management, demand management, product management, and information management (Tang, 2006)

It has been suggested by Jüttner (2005), that supply chain risk management has three pillars: philosophy, principles, and process, commonly known as the 3Ps. The term philosophy refers to comprehensive beliefs that encourage change in a stable system in either the short-term or the long-term. There are two critical elements related to philosophy, the requirement for an openness to share information risk and the readiness to approve risks in a supply chain as a joint responsibility. A driving force, organization, holistic risk management, and cross-border cooperation are all aspects that included in the philosophy pillar of supply chain risk management.

The principle pillar of supply chain risk management should be an integrated aspect of the supply chain strategy, as principles construct the criteria for both the strategic and the operational risk management processes in a supply chain. Planning of the supply chain and structure, visibility, cooperation, and communication are developed as requirements for implementation or process of risk management within a supply chain.

Processes are clearly identified as being activities, methods, and tools, while being specifically identified as inputs and outputs, and containing a detailed structure of activities within and across a company's structure. Figure 4-1 shows the 3Ps of supply chain risk management.

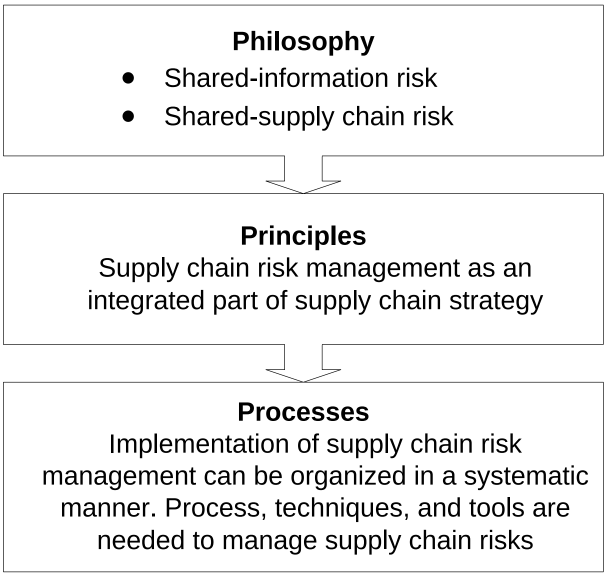


Figure 4- 1: The Philosophy, Principles and Processes of supply chain risk management
Source: Chapman et al., (2002); Jüttner (2005)

4.2.2 The Steps of Supply Chain Risk Management

The steps involved in supply chain risk management consist of risk identification, risk assessment, risk treatment and risk monitoring (Norrman & Jansson, 2004). Identification of risks within the company, supply chain, and environment is typically the first step in detecting potential risks. Assessment of identified risk begins by estimating probability for an event to occur as well as its anticipated impact. Afterwards, risk treatment is conducted to decide which strategies and measures should be employed to minimize the risks. Finally, the monitoring process should be a continuous comparison of the target against the actual risk portfolio, so that a quick response can be executed.

Similarly, Kleindorfer and Saad (2005) specified the following three tasks of supply chain risk management: Specifying sources of risk and vulnerabilities, assessment, and mitigation. Other researchers have similar understanding of the steps which are necessary to include in supply chain risk management. Khan and Burnes (2007) argued that there are three critical stages in supply chain risk management: 1) Risk identification in order to determine the risk factors that are likely to occur in an event; 2) Risk analysis to understand the frequency and its impact on an event, and 3) Risk evaluation to determine the most suitable strategies for reducing reduce the identified risks. Manuj and Mentzer (2008) extended the stages of Khan and Burnes to include risk identification, risk assessment and evaluation, selection of appropriate risk management approaches, implementation of strategies, and mitigation of supply chain risks.

Manuj and Mentzer (2008) described an insightful base for implementing supply chain risk management, which offers detailed tables for risk identification, risk assessment and evaluation, and risk management strategy aspects. The phases of Supply Chain Risk Management Process (SCRMP) are identifying, measuring and assessing risk; risk evaluation, risk mitigation and contingency plans; and risk control and monitoring with data management systems (Tummala & Schoenherr, 2011).

Despite the variety of supply chain risk management processes that have been suggested, this paper will adopt the process suggested by Khan and Burnes, (2007) as well as Sodhi and Tang (2012). The first three stages, risk identification and categorization, risk assessment, and risk mitigation should be performed prior to the occurrence of the negative event. The risk responses are taken during and after the occurrence of an incident (Sodhi & Tang, 2012).

4.2.3 Related Studies of Supply Chain Risk Management

The topic of supply chain risk management is becoming an important issue for researchers and professionals (Narasimhan & Talluri, 2009). Papers pertaining supply chain risk management are published in many different journals, indicating its multidisciplinary field. There are both quantitative and qualitative studies published in many international journals and some monographs. The majority of the papers on managing supply chain risks are focused on the theoretical framework as a platform for future researchers. In the last decade, there have been an increasing number of empirical studies relating to supply chain risk management.

The list of journals containing supply chain risk management are divided into three main groups, according to the classifications of Tang and Musa (2011): 1) Business or management reviews including MIT Sloan Management Review, Harvard Business Review, and Supply Chain Management Review, 2) Operations and Supply Chain Management Journals: International Journal of Logistics Management, International Journal of Operations and Production Management, International Journal of Physical Distribution and Logistics Management, Production and Operation Management, and Supply Chain Management: An International Journal, Journal of Manufacturing Technology Management, and 3) Management Science/Operation Research journals: European Journal of Operation Research, International Journal of Production Economics, International Journal of Production Research, and Omega.

The studies related to supply chain risk originated in the 1960s and 1970s, but were often conducted as separate in supply and demand aspects (Khan & Burnes, 2007). Robinson et al. (1967) conducted a study on the organizational buying behavior study with the Buy Grid Model and Williamson (1979) introduced Transaction Cost Economics (TCE), which is applied in the Industrial Marketing and Purchasing (IMP) Group. Kraljic (1983) was the initial scholar who included risk as part of supply management. He proposed a model which classifies purchasing materials as being aspects of profit impact and supply risk. The classification of purchasing materials is assessed by availability, number of suppliers, competitive demand, make-or-buy-opportunities, storage risks, and substitution possibilities.

Kraljic's study has influenced several researchers to develop concerns related to supplier risks and supply networks (Giunipero & Aly Eltantawy, 2004; Hallikas et al., 2002; Harland et al., 2003; Ragatz et al., 2002; Zsidisin et al., 2004; Zsidisin et al., 2000). Furthermore, many papers on supply networks have inspired researchers to explore the in-depth the relationship between risk and supply chain management. Previous studies of supply chain risk management can be classified into two categories, theoretical approaches and empirical research.

4.2.3.1 Theoretical Approach

Some scholars have provided conceptual frameworks, guidelines and systematic literature surveys, and co/citation analyses of supply chain risk management. Tang (2006) reviewed basic conceptual models for managing supply chain risks and provided strategic and tactical plans based on supply management, demand management, product management, and information management. He also explained a specific practical guide intended especially for mitigating supply chain risks.

Khan and Burnes (2007) developed a research agenda for supply chain risk management, in which they reviewed literature regarding risk in terms of qualitative and quantitative approaches. Furthermore, they analyzed how risk theory and risk management can be applied to the concept of supply chain management. Manuj and Mentzer (2008) demonstrated an integrated conceptual framework and developed a step-by-step guide for empirical research on global supply chain risk management (Tummala & Schoenherr, 2011) contributed a conceptual framework called the Supply Chain Risk Management Process (SCRMP), which offers a framework and decision making support guide that is especially useful for managers.

Furthermore, De Waart (2006) suggested a comprehensive approach in order to manage supply chain risks, which is known as SMART: Specific, Measurable, Actionable, Realistic, and Time-Phased. The term measurable means that the risks and their potential impacts should be quantified. Actionable relates to how assessed risks are minimized by creating definite mitigation actions or feasible strategies. The concept of a realistic approach indicates an understanding of what sources are needed to reduce risks and prioritize to consider any limitation of resources. Time-phased refers to the implementation of a decision with explicit roles and responsibilities. When these aspects are taken into consideration, specific risks and their impacts should be identifiable.

Several scholars have investigated systematic literature surveys and citation/co-citation analyses in the articles of selected journals in connection with supply chain risk management. The results are used as a basis for understanding research gaps which are further developed as a guideline for future researchers in supply chain risk management. Vanany et al. (2009) classified supply chain risk management papers according to the approaches and methodologies used. Moreover, the divided the articles into five categories based on used approaches: conceptual, descriptive, empirical studies, exploratory cross-sectional, and exploratory longitudinal studies. These literature surveys were conducted with journal articles written from 2000 to 2006.

Tang and Musa (2011) analyzed articles in selected journals of supply chain operations management from 1995 to 2009. From 2000 to 2005, a substantial increase in publications relating to supply chain risk management was recognized. Their paper guided in identifying and categorizing potential risks regarding the flow of material, information, and finance. The solutions for mitigating the risks are divided into qualitative and quantitative methods. They showed that studies on quantitative models in managing supply chain risk are relatively rare. A recent study by Heckmann et al. (2015) supported their findings in that the research challenges of supply chain risk management are studies regarding quantitative and modeling approaches.

Wilding et al. (2012) identified the development of supply chain risk management theory. They concluded that supply chain risk can be managed by considering uncertainty in supply chain planning, by understanding the impact of risk coming from collaboration and interaction amongst supply chain members, and by developing proactive mitigation strategies to reduce the risk levels.

Ghadge et al. (2012) further examined important strategic changes and research challenges in supply chain risk management. They identified the most appropriate strategies based on a systematic literature survey of the 140 quality articles which were published on the topic from 2000 to 2010.

4.2.3.2 Empirical Research

Previous researchers have indicated the necessity of various combinations of conceptual and empirical research. What is known about supply chain risk management is largely due to empirical studies that investigate how the concept can be applied in a real business setting. Other studies, however, conducted a practical research to build a theoretical framework. The previous empirical studies can be listed as applying the steps of supply chain risk management, analyzing the relationship between supply chain risks and supply chain's performance, identifying key success factors for managing supply chain risk and mitigating supply chain risks.

Most concepts related to supply chain risk management have been applied in case studies, particularly in the manufacturing industry. The importance of supply chain risk management has grown much more rapidly in the manufacturing sector than in the service industry. In the service industry, fewer supplies are generally needed when compared to the manufacturing sector (Kersten et al., 2006). Similarly, there are only a few publications with regard to supply chain risks in the agri-food industry. Most of the empirical case studies in these cases were only conducted with respect to the farm perspective, particularly in land-based agricultural products.

Jüttner et al. (2003) conducted an interview regarding the perception of supply chain risk management from practitioners in manufacturing, retail, logistics and service providers. The result of this survey was summarized as an outline agenda for future research. Kersten et al. (2006) also asked industrial and logistic service providers about the importance of supply chain risk management. Afterwards, they described the methodological concepts with a common risk management guideline for the supply chain and its implementation within the company to serve as additional education on the topic.

Harland et al. (2003) have identified many definitions of risk, as well as having developed a risk categorization. They also developed tools to identify, assess, and manage risk within supply networks utilized in the electronics sector.

Norrman and Jansson (2004) described and shared how Ericson has developed and implemented a new organization, processes, and tools in order to minimize risk exposures in the supply chain. After a major accident at a sub-supplier, Ericsson developed a tool called the Ericsson Risk Management Evaluation Tool (ERMET), which evaluates many aspects such as business control and financial issues, as well as being able to analyze internal and external suppliers. Ericsson has also developed a template for risk assessment and risk treatment along with contingency plans. The article concludes that the risk, time, cost, quality, agility, and leanness should be considered as part of a trade-off analysis when evaluating new logistics solutions to find the most efficient level of risk and prevention.

Previous studies have reported that there is a relationship between several risk factors and the performance of the supply chain. Wagner and Bode (2008) analyzed the concept based on cross-sectional research in Germany which interviewed top-level executives in logistics and supply chain management in industrial (71.7%), services (19.5%), and trade companies (8.8%). The research showed that supply and demand risks have a negative impact on the supply chain performance. On the other hand, there is no significant effect on regulatory, legal and bureaucratic risks, infrastructure risks and catastrophic risks, as well as no significant effect on the overall performance of the supply chain. Furthermore, Kleindorfer and Saad (2005) examined the risks in the chemical industry which arise from natural disasters, strikes and economic crises, and terrorism. They developed a conceptual framework that reflects the effective integration of risk assessment and risk mitigation processes.

Raj Sinha et al. (2004) presented a generic method in the aerospace supply chain called IDEFO (integrated definition), a method that is employed to develop a functional or activity model of an enterprise. The process consists of brainstorming to identify risk, identify field of risks, classify the risk, risk assessment, prioritized risk, plan and implementation solutions, conduct failure mode and effect analysis, and to conduct continuous improvement.

Trkman and McCormack (2009) argued that supply risk is a major challenge in supply chain management. The critical first step of the process of managing supply chain risk is the ability to recognize which supplier has the greater potential for enhancing supply chain performance. A new method to identify and predict supply risks which assesses and categorizes suppliers is based on suppliers' attributes, performances and supply chain characteristics, as well as their specific environment.

Key factors for successful supply chain risk management are better communication amongst members of the supply chain, training programs related to supply chain risk management and business continuity management, and a risk manager that specializes in the management of supply chain risks. Blos et al. (2009) highlighted the importance of carrying out supply chain risk management through the use of an exploratory study where they described how the automotive and electronic industries in Brazil have successfully applied the concept.

Similarly, Lavastre et al. (2012) found that effective supply chain risk management relies on collaboration activities such as collaborative meetings, timely and relevant information exchanges, and initiation of shared information with its partners. For their research, 142 general managers and logistics and supply chain managers from 50 French companies were interviewed.

An empirical analysis of the supply chain risk process is described by Thun and Hoenig, (2011) based on a survey of 67 automotive manufacturers in Germany. The findings are depicted in the probability and impact matrix with risk differentiating between internal and external supply chain risks. Two instruments are available for managing risk within the supply chain: reactive and preventive approaches. The preventive supply chain risk management has better values in flexibility and safety stock than the reactive actions.

Another important element of managing supply chain risk is product design. Design-led risk management is a critical element especially in industries with shorter product life cycles such as the textile and clothing industries. Khan et al. (2008) conducted an in-depth longitudinal case study in the largest clothing manufacturing and fashion retailer in the UK. Data collection was conducted through several methods, namely supplier workshop, semi-structured interviews, company documentation and archives. Two points stand out in this study: the company has developed a formal, systematic procedure in order to manage supply chain risk, as well as an in-house product design that is central to the company's ability to manage the risks.

Faisal et al.(2007) measured the mitigation of supply chain risks applied to a medium enterprise using a combination of the Analytic Network Process (ANP) and the Supply Chain Operations Reference (SCOR) model. The proposed model helps supply chain managers to simultaneously consider different types of risks and their interdependence, as well as to learn from feedback in order to select the best alternative to manage risk in supply chains.

Several relevant studies investigating risks in agriculture or agri-food supply chains have been conducted since 2010. The World Bank (2012) carried out an empirical study of a coffee supply chain risk assessment in Uganda. The report indicated that risk sources are categorized into three main factors: production (pest and disease outbreaks, and climate), market (price, foreign exchange risk and loss of global market share), and environmental risk (transport-related risks, theft, fraud, and adulteration). Supply chain risks are assessed by frequency and the extent of impact for an event.

Following the World Bank study, Sarpong et al. (2013) examined the various categories of risks within the cocoa supply chain in Ghana. The study identified that the major risks in the cocoa supply chain are diseases, exchange rate volatility, and smuggling. In order to mitigate these risks, supply chain members should improve information sharing and trust building between one another, as well as coordination and integration. A study by Leat and Revoredo-Giha (2013) indicated that a resilient supply chain can be achieved through two critical strategies, horizontal collaboration between producers, and vertical collaboration with the processor and retailers. The research was conducted in one of Scotland's major pork supply chains involving in-depth interviews with the chain members and its management personnel. They classified risks into supply networks risks, institutional risks, human or personal risks, and financial risks.

Yeboah et al. (2014) investigated and identified the probable supply chain risks of major agricultural products in Ghana. The results show that while some risk sources could be managed, others have no available management strategies. Apte (2010) developed a conceptual framework related to vulnerability of food supply chain disruptions. The vulnerability factors due to contamination of a perishable product; these factors include product type, topological structure, exposure to contamination, product traceability, and communication. This framework was developed based on an in-depth study of a single case in the US.

In the food sector, maintaining product quality is the critical factor in a global supply chain. Despite the risks from a member of a supply chain being minor disturbances, their cumulative effect can become very significant. A case study by Chavez and Seow (2012) was conducted on a food distributor, SME Ltd., in Central America to investigate how product quality risks are managed based on integrated supply chain risk management.

Shen et al.(2013) categorized agri-food supply chain risks into technical risks, information risks, organizational management risks, and security risks. The risks can be assessed through the Analytical Hierarchy Process (AHP) and with the use of fuzzy comprehensive evaluation methods.

In the fisheries field, Fitrianto and Hadi (2012) suggested conducting empirical research of supply chain risk management on the shrimp industry before and during a mud volcano in Sidoarjo, Indonesia. It was suggested that a field survey to collect data.

4.3 Identification and Categorization of Supply Chain Risks

The second objective of this study is identifying and categorizing the seaweed supply chain risks. Risk identification is the first step in determining possible sources of risk in a seaweed supply chain. A company must identify the potential causes or sources of those risks at every significant link along the supply chain (Christopher et al., 2002). Risk identification refers to the recognition of sources of risk-hazard and factor-peril resources exposed to risk. Risk identification helps decision makers become aware of events that may cause disturbances (Normann & Jannson, 2004). Risk identification is a continuous process and continually seeking new risks as a pillar for potential future work (Tchankova, 2002). As Chopra and Sodhi (2004) mentioned, some of the leading manufacturers such as Dell, Toyota and Motorolla possess a great ability to identify their supply chain risks and are able to mitigate the negative effects.

Categorization of risk within the supply chain can be difficult (Chopra & Sodhi, 2004). Many categories of supply chain risk are often labeled as supply chain risk sources, which arise from interactions between organizations in the supply chain (Jüttner, 2005).

Risks in a supply chain can be generated through both internal and external factors. Internal factors can arise from coordination problems within the firm (process and control, amongst other risks) and internal to the supply chain (supply and demand risks). External risks to the network appear as consequences from environmental, economic, and social events (Christopher & Peck, 2004; Jüttner, 2005; Jüttner et al., 2003; Kersten et al., 2006; Pfohl et al., 2010; Sodhi & Tang, 2012).

Jüttner et al. (2003) categorized risk sources into three groups: organizational risks, supply chain network risks, and environmental risks. Organizational risk sources are those risks within an organization which relate to production uncertainties, human resources or the disruption of a production system. Network risks arise from interfaces between the members of a supply chain. Environmental risks are any risks that result from the supply chain-environment interaction such as socio-political activities, natural disasters or accidents. Similarly, Christopher and Peck (2004) suggested that supply chain risk categorization is grouped into five categories: process and control risks as internal firm risks; supply and demand risks as external risks to the firm, but internal to the supply chain; and external to the network risk.

Risks that are internal to the firm include process risk, control risk and other risks which cover finance, marketing, human resources, and information technology. Process risk refers to interruptions in the sequential process intended to improve added value of products or services. This risk is the probability of an event's occurrence associated with a focal firm that may failure in product design, production, capacity, inventory, yield, quality and machine breakdowns (Jüttner et al., 2003; Pfohl et al., 2010; Sodhi & Tang, 2012; Svensson, 2000).

Control risks arise from disturbances in the rules of a company's planning and management activities, systems, and procedures that drive how a company applies control over the process, for example, order quantities, batch sizes, inventory management, and forecasting. Control risk can be associated with an event that negatively affects inventory, such as inappropriate scheduling, delays in delivery, and a lack of collaborative planning between suppliers and focal processors (Jüttner et al., 2003; Pfohl et al., 2010; Sodhi & Tang, 2012; Svensson, 2000).

Risks that are external to the firm, but internal to the supply chain are comprised of supply and demand risk. Supply risk is the probability of an event concerning that affects inbound supply and may cause failures in the flow of materials, information, and finance from suppliers to the focal firm. The failures may arise in supply cost, delivery, quality, and commitment (Christopher & Peck, 2004; Pfohl et al., 2010; Sodhi & Tang, 2012; Svensson, 2000; Tang, 2006; Zsidisin et al., 2000).

Demand risk refers to potential disruptions to the flow of goods, information, and cash flow between focal companies and other players on the downstream side of the chain to issues dealing with both volume and actual product. These risk sources can originate from errors of forecasting between companies' forecasted and actual demand; and changes in technology or in consumer preference. may impact the ability of a customer to place orders with the focal firm, and variance in the volume and variety desired by customers (Christopher & Peck, 2004; Pfohl et al., 2010; Sodhi & Tang, 2012; Svensson, 2000; Tang, 2006; Zsidisin et al., 2000).

External risk relates to environmental occurrences which may directly impact a specific actor of a supply chain. The risk is outside the control of the firm and the supply chain, despite it having an impact on all members of a supply chain. External risk may be the result of disturbances related to socio-political, economy, infrastructures, legal issues and technological events, environmental damages, and natural disasters. It is also influenced by global conditions and community behavior (Christopher & Peck, 2004; Pfohl et al., 2010; Sodhi & Tang, 2012; Svensson, 2000; Tang, 2006; Zsidisin et al., 2000).

Other researchers, however, did not explicitly refer to external aspects as risk sources. Sodhi and Tang (2012) classify supply chain risk sources into four groups: supply risks, process risks, demand risks, and corporate level risk. Corporate level risks emerge from financial risks, supply chain visibility, political, social risks, information and technology systems risk, loss of intellectual property, exchange rate, environmental risk and compliance costs, and regulation compliance.

In other papers, supply chain risk is classified into five sub-categories: physical, financial, informational, relational, and innovational risk (Cavinato, 2004; Spekman & Davis, 2004). Risks to physical sub-chains cover logistics in the form of transportation, warehousing, handling, processing, manufacturing, and other utility activities. Financial risks deal with the flow of money along a supply chain. Informational risks are related to the process and electronic systems used for creating events, triggering product movements, and service mobilization. The relational sub-category relates to linkages between buyers, sellers and the logistic providers that operate between the buyers and sellers. Innovation risks cover the risks within the firm and among its customers, suppliers and other parties to reach higher market share, process innovation and service assistance. Chopra and Sodhi (2004) categorized supply chain risks into disruptions, delays, systems, forecast, intellectual property, procurement, receivables, inventory, and capacity. In this study, the categorization of risk sources within the supply chain followed the definitions of Jüttner (2005) and Christopher and Peck (2004). Originally, this framework comes from Mason-Jones and Towill (1997). A generic model of the risk sources within a supply chain is described in Figure 4-2.

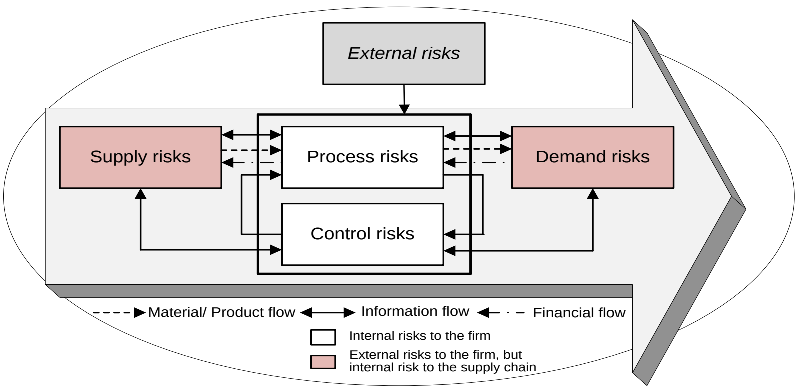


Figure 4-2: Generic model of risk sources within a supply chain

Adapted from Mason-Jones and Towill (1997), Christopher & Peck(2004), and Jüttner, 2005)

4.4 Identification and Categorization of Seaweed Supply Chain Risks

In this research, the sources of a seaweed supply chain risk are categorized into two groups: internal and external risks. The internal risks cover internal risks to the firm and external risks to the firm, but internal risks to the supply chain. Internal risks can be handled by the firm and or members of the supply chain. Most external risks, however, cannot be overcome by the firm or supply chain, particularly with regards to finance, policy, infrastructure risks, and risk caused by natural disasters.

Internal risks cover the risks within the company which consists of process and control risks, while the risks within the seaweed supply chains are comprised of supply and demand risks. In terms of external risks were sustainability elements, specifically with respect to environmental, social and economic criteria. Ghadge et al. (2012) mentioned that sustainability factors have a larger influence in designing a supply chain. Moreover, external risks are risks outside of companies and supply chains, which include financial, policy and infrastructure risks, social risks, and environmental risks. Figure 4-3 presents the sources of seaweed supply chain risks. The sources and their effects are explained in detail in Section 4.4.1.

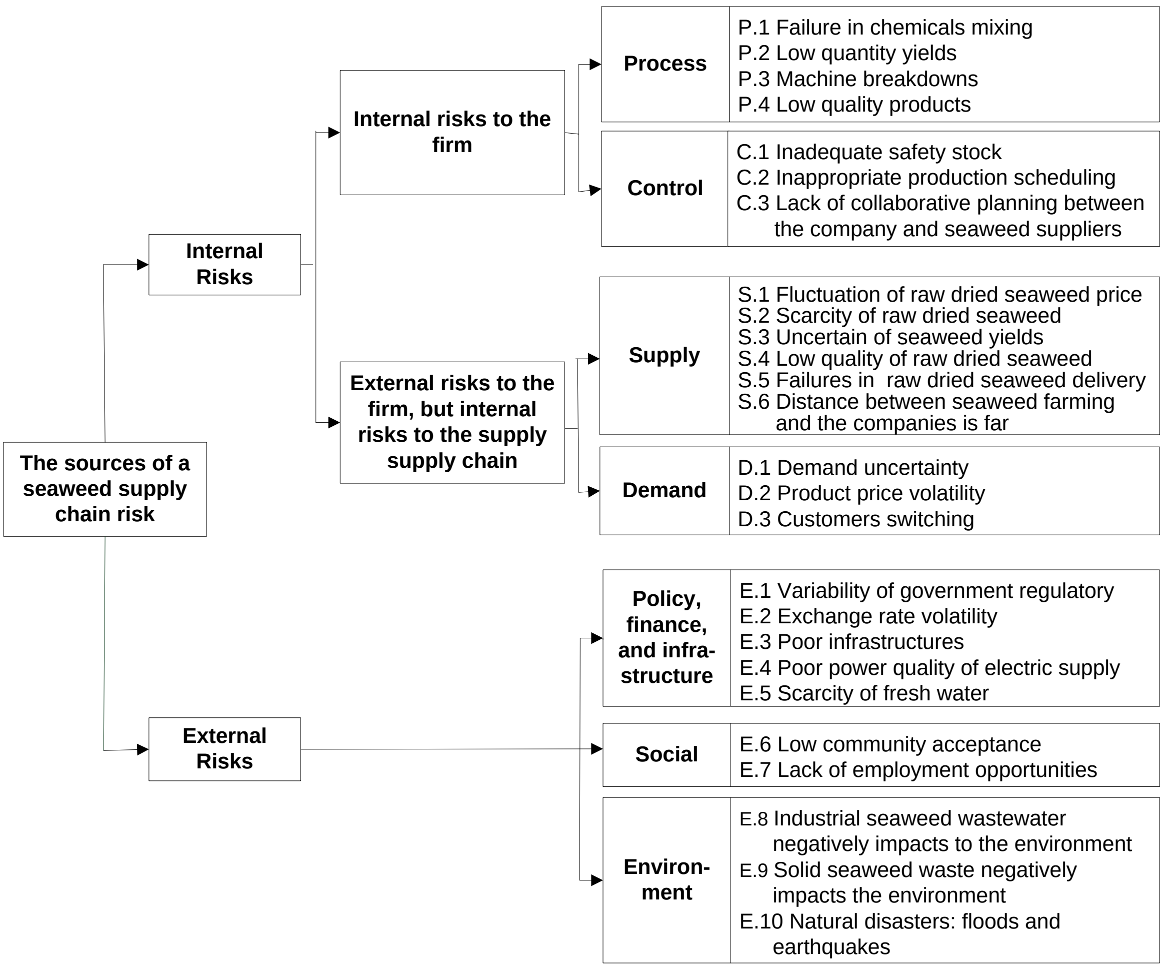


Figure 4-3: The sources of seaweed supply chain risk

Adapted from Christopher & Peck (2004); Sodhi and Tang (2012); Vlajic, van der Vorst, & Haijema, 2012

Methods of risk identification are classified into intuitive, inductive, and deductive approaches. Brainstorming is particularly useful in the intuitive approach, as it offers a quick and simple way to get information. However, this technique lacks the input of comprehensive data since it is only based on qualitative information. The inductive, or ‘what if’, analysis is used to begin with detailed observations and move towards generalized results. The most commonly inductive methods in risk identification are preliminary Hazard and Operability Studies (HAZOPS), checklists, and Failure Modes and Effects Analysis (FMEA). The deductive method indicates the result of an investigation and analysis which utilizes event and fault trees as a primary technique (Frosdick, 1997).

In this study, the key respondents for identifying and categorizing seaweed supply chain risk were limited to carrageenan companies, agar companies, large traders, and seaweed farmers. The information was also provided by seaweed experts from the Indonesian Institute of Science (LIPI) and *Jaringan Sumber Daya (Jasuda),* a non-government organization (NGO) in South Sulawesi, All participants were top level managers and included those in roles such as owners, directors, production managers and quality managers. A more detailed breakdown of the data sample and details on the respondents can be found in Table 4-1. On average, the respondents had worked in this position for seven years and had been with the firm for eleven years.

Table 4-1: Respondents for risk identification in the seaweed supply chain

No	Company	Province	Location
1. Carrageenan companies			
1.1	PT Bantimurung Indah	South Sulawesi	Maros
1.2	PT Wahyu Putra Bima Sakti		Makassar
1.3	PT Amarta Carrageenan	East Java	Pasuruan
1.4	PT Hakiki Donarta		Pasuruan
1.5	PT Galic Arthabahari	West Java	Bekasi
1.6	PT Hydrocolloid Indonesia		Bogor
1.7	PT Gumindo Perkasa	Banten	Banten
1.8	PT Phoenix Mas	West Nusa Tenggara	Mataram
2. Agar companies			
2.1	PT Agar Swallow	West Java	Bogor
2.2	PT Surya Indo Algas	East Java	Sidoarjo
3. Large traders			
3.1	Kospermindo (cooperative)	South Sulawesi	Makassar
3.2	PT Rapid Niaga Internasional		Makassar
3.3	CV Bina Makmur Sejahtera	East Java	Surabaya
4. Seaweed farmers			
4.1	Indonesian Seaweed Farmers and Processors Association	South Sulawesi	Makassar
4.2	Individual seaweed farmer of *E.cottonii*		Takalar

Source: Field research in April 2013

In order to identify the risks of a seaweed supply chain, the Delphi method and a site visit to supply chain members were used to analyze the potential risk sources and their impacts. The method was conducted by an individual expert; specifically, a production or a supply chain personnel who has an understanding of the particular system. The Delphi method is a step-by-step method which focuses on potential risks and their effects. A risk checklist can also be utilized as a tool to identify risks, as well as for considering risk sources, their causes and their impacts.

The first step of this process was to design the questionnaire based on extensive theoretical reviews on supply chain risk sources. Operational definitions for each risk source were derived from these sources. The questionnaire contains questions pertaining to the causes of risk and their impacts. Following this, questions were posed through semi-structured, face-to-face interviews took on average two hours. The first questionnaire was revised on the basis of comments from practitioners and experts. Following this step, their comments were incorporated into the final version of the questionnaire (see Appendix 1). Respondents were asked to indicate how their firms had been affected during the last five years (2009 to 2013) by supply chain disruptions and what the effects of these impacts were. The next section describes the sources, their causes, and their impacts of seaweed supply chain risks.

4.4.1 Internal Risk to the Firm

Internal risks of the firm are classified into two elements: process risks and control risks. Risk sources, causes, and effects of internal risk will be explained in the following section.

4.4.1.1 *Process Risks*

Process risks are disturbances of carrageenan and agar seaweed production. The major sources of these risks are failure in chemical mixing, low product yields, machine breakdowns, and poor quality of products.

P.1 Failure in chemical mixing

The respondents identified that a failure in chemical mixing is mainly caused by human errors. The necessary chemicals for seaweed production are sodium hydroxide and potassium hydroxide. Mixing errors refer to mistakes caused by humans and not machines in a particular working condition. Another cause of problems in chemical mixing is the workers in the production line that are not knowledgeable about the importance of quality products both for carrageenan and agar. Often, the workers do not fully understand the chemical mixing process for seaweed manufacturing. If quality control is rarely conducted during the chemical mixing production process, mistakes by laborers are increased. Some respondents argued that a lack of Standard Operating Procedures (SOPs) to produce carrageenan and agar may have contributed to many mistakes in chemical mixing. A failure in the chemical mixing process is clearly visible in the extraction process due to the imbalance in the ratio between water volume and chemicals.

Failure in chemical mixing may have increased because products were unable to meet customer demand. When customer demand is not met, a rise in negative claims, typically in the form of returned products, is noticeable. If chemical materials are mixed without taking into consideration the required standards, excess wastewater is added to the environment. Furthermore, a local community could protest a company due to concerns over water pollution and disruptions to their activities. Occasionally, claims from customers and surrounding communities can influence a company's financial flow and gradually cause a loss in profit.

P.2 Low products yields

A low product yield means that the total output quantity of carrageenan and agar are low. Low yields can result from multiple factors, namely low quality of raw dried seaweed, mistakes in the adjustment of pH values, and temperature variances, and errors in the selection of the alkali solvents.

The quality of raw dried seaweed mainly determines the total product yield. A company must check the moisture content, as well as the amount of foreign materials such as sand, soil, insects and plastics before further processing. A high moisture content (> 32% for *E. cottonii* and > 18% for *Gracilaria*), along with a large amount of external materials (>5%), leads to a decrease in the overall volume of carrageenan and agar.

Mistakes in establishing the correct pH value and the required temperature often occur during production. Careful control of the pH value and temperature is needed to obtain optimum yields. For instance, the filtration process of refined carrageenan production requires special attention to temperature since clarity and purity depend significantly on the proper application of this process. In order to catalyze the gel product, the temperature should be between 70-130^{0}C; it is critical that the temperature does not exceed 130^{0}C to prevent any degradation of the kappa carrageenan (Mishra et al., 2008).

Selection of the alkali solution is based on different salt types of seaweed because it will affect the properties of the product, such as thickening and gelling ability (Bono et al., 2012). For *Gracilaria,* a stronger chemical material is required to improve the agar gel strength.

If low product yields become a consistent issue, companies will likely find it difficult to meet consumer demand and account for disparities between actual capacity and design capacity. In the long-run, a company will notice a decrease in their profits and consumers will switch to other producers.

P.3 Machine breakdowns

Machine breakdowns are generally due to raw dried seaweed still containing sand or other foreign materials, and issues dealing with machine maintenance and repair. Repairs are rarely conducted and many companies are still using old machines with an unstable supply of electricity. The electric power supply can occasionally be interrupted during production, an external factor that can cause machine breakdowns.

Also, cleaning up the sludge or other materials that are attached to the processing machines is rather difficult. Therefore, it may cause corrosion on the machines. Machine maintenance and repairs should be conducted as preventive actions to minimize machine breakdowns.

Machine breakdowns contribute to the downtime of production systems. As a result, target outputs of carrageenan and agar might be not in accordance with the initial planning. Delivering products to consumers, both domestically and internationally are delayed because the required production time longer than usual

P.4 Low quality products

International food grade specifications exist for carrageenan and agar seaweed, for example the European Union (EU) legislation on Food Additives and International Food Standards, the Codex Alimentarius Commission, the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). The EU has made regulations of specifications for food additives in the Commission Regulation (EU) No 231/2012 of 9 March 2012. The specifications of semi-refined carrageenan (SRC), refined carrageenan, and agar are listed in Annexes II and III to Regulation (EC) No. 1333/2008 of the European Parliament and of the Council. However, carrageenan and agar producers occasionally do not fulfill the quality requirements.

Product quality risk in a supply chain can be defined as ‘a product’s quality state in which it is affected by direct and indirect multi-tier suppliers materials, in which a minor risk incident can have cumulative effects along the whole network’ (Chavez & Seow, 2012). The primary cause of low quality is generally that raw materials still have higher moisture content than the required standard, more than 35%. A company should start drying immediately to protect the raw materials from any degradation of microorganisms.

Human errors in the adjustment of the method, temperature, and duration of extraction processes influence the quality of products. For carrageenan products, this view is supported by Dewi et al. (2012) who conducted the research of characterization and quality of SRC. Low product quality leads to decreasing prices and declining market shares in domestic and global market. Table 4-2 summarizes the causes and impacts of internal risks in the focal company.

Table 4-2: Process *risk sources with their causes and effects of carrageenan*

No	Risk source	Causes	Effects
P.1	Failure in chemicals mixing	• Human errors. • Workers are not knowledgeable about product quality • Workers do not understand the chemical mixing process of carrageenan and agar • Lack of quality control • Lack of SOP	• Product specifications do not match customer demand • Increased customer claims • Excess wastewater • Loss of profit
P.2	Low quantity yields	• Low quality of raw dried seaweed • Mistakes in adjustment of the pH value and the temperature • Errors in selection of the alkaline solutions	• Difficult to fulfill consumer demand • Mismatch between actual and design capacity • Consumers will switch to other producers
P.3	Machine breakdowns	• Raw dried seaweed contain foreign materials • Lack of preventive maintenance • Use of old machines • Unstable supply of electricity	• Increasing downtime • Change of output • Delay on product delivery
P.4	Low quality products	• Low quality of raw dried seaweed • Human errors in the adjustment of method, temperature, and extraction times	• Decreased product prices • Decreased market share

4.4.1.2 *Control Risk*

The causes of control risk in seaweed production are when the safety stock is not sufficient, production scheduling does not match with planning, and there is a lack of collaborative planning between seaweed farmers and the companies. These sources are the major drivers of control risks in the company.

C.1 Inadequate safety stock

A company should have an efficient inventory, with a safety stock representing one of the most important factors in preventing possible break downs in a supply chain (Amirjabbari & Bhuiyan, 2014). Stock out of safety stock is a major problem within a company that affects the entire supply chain.

Uncertain and high demand for products, especially carrageenan demand, can lead to stock running out. In addition, scarcity of raw dried seaweed caused inadequate safety stock. Carrageenan companies in Indonesia cannot buy raw dried seaweed because they cannot compete with other buyers from abroad such as China and Japan. Some importers buy raw dried seaweed at a higher price. Another reason for running out of stock is a long lead time of chemical materials from other countries.

C.2 Inappropriate production scheduling

Production scheduling problems between actual production and its planning appear because of system errors to plan raw materials, labors, and machines. Several companies do not have a robust production scheduling system. Another major cause of resources misallocation is caused by delivery of chemical materials which takes on average of two to three months. Most materials are imported from other countries such as China. A mismatch might also occur in production scheduling due to interruptions to production machines. It is important to synchronize all the main resources: raw materials, laborers, and machines to achieve best performance of a company. Otherwise, a company cannot meet the consumers' demands.

C.3 Lack of collaborative relationship between the focal company and seaweed suppliers

According to Anthony (2000), a collaborative relationship has two essential elements, consisting of shared information between companies and drivers of change to the basic business. Most of carrageenan and agar companies interact with their suppliers by telephone, which it communication cost was relatively high.

Another cause of the risk is the long-distance between seaweed suppliers and carrageenan and agar companies. On average 73% of carrageenan and agar companies are located in Java Island. More than 70% of seaweed suppliers, on the other hand, are founded in Sulawesi Island. For example, the distance between an agar company in Tangerang, a sub-province in Banten province, Java Island, and seaweed farmers in Takalar, a city in South Sulawesi, Sulawesi Island, is 1,421.82 km.

Communication costs and distance have contributed to a distortion of information particularly between focal companies and seaweed suppliers. Misunderstandings among these members occur frequently, often due to standard requirements of raw materials. Another relevant impact of a lack in collaborative relationships is that problems cannot be handled quickly. Table 4-3 describes control risk resources with their causes and effects.

Table 4- 3: Control risk sources with their causes and effects

No	Risk source	Causes	Effects
C.1	Inadequate safety stock	• Uncertain and high demand of products • Scarcity of raw materials • Long lead time of chemical materials	• Interrupted production
C.2	Inappropriate production scheduling	• Forecasting does not match actual production • Long lead time of chemical materials • Errors in production system	• Decreased of consumer trust
C.3	Lack of collaborative planning between the focal company and seaweed suppliers	• Large distances between seaweed suppliers and focal companies • High cost of communication	• Distortion of information • Problems cannot be handled quickly enough

4.4.2 External Risk to the Firm, but Internal Risk to the Supply Chain

4.4.2.1 *Supply Risk*

Supply risks that exist in the seaweed supply chain result from fluctuations in the price of raw dried seaweed, scarcity of raw dried seaweed, uncertainty of seaweed yields, quality problems, delivery failure, and long distances between seaweed suppliers and focal companies. An extreme failure of supply may influence the shut-down of production which consequently can result in the loss of business and customers.

S.1 Fluctuation of raw dried seaweed price

Whole traders who also act as exporters determine the price of raw dried seaweed. A price mechanism has not been specified by a standard regulation. The price, in particular *E. cottonii* fluctuates because 80% of *E. cottonii* is influenced by global demand. The price has also been driven by increasing demand, mainly from China and the Philippines. Therefore, there are limited supply conditions in the domestic market. Competition among global carrageenan companies, mainly in China and the Philippines, can result in increasing sale prices of raw dried seaweed. Moreover, the quality of raw dried seaweed also contributes to price variances.

The price of raw dried seaweed plays a critical role in the financial performance of carrageenan and agar companies. Price fluctuations disturb the cash flow of seaweed supply chain members, particularly seaweed farmers and focal companies.

S.2 Scarcity of raw dried seaweed

Seaweed farmers have limited access to financial institutions both in credit and savings. Lack of financial capital means that many farmers are unable to continuously cultivate seaweed. Even if financing is available, farmers often face very high interest rates and unfavorable borrowing conditions. This condition makes it particularly difficult for carrageenan and agar companies to obtain raw dried seaweed.

The growing global market demand for raw dried seaweed especially to produce carrageenan, mainly from China (55%), influences the overall availability of raw materials. Large quantities of seaweed, especially for *E. cottonni* are purchased at low prices. Currently, the stocks of raw dried seaweed in Indonesia are declining, so that carrageenan companies have difficulties getting raw dried seaweed from domestic supplies. In addition to problems of scarcity of raw dried seaweed, most seaweed farmers have a very limited availability of good seedlings.

A decrease in the availability of raw dried seaweed interrupts the flow of materials in a seaweed supply chain. Consequently, the production schedule is interrupted, which could potentially lead to an increase in production costs. Focal companies are willing to purchase raw dried seaweed at a higher price when overall availability is on the decline.

S.3 Uncertain seaweed yields

The major cause of uncertain seaweed yields is seasonal variability in different regions. Indonesia has a tropical climate with a dry season (April to September) and a wet season (October to March); temperatures, however, do not vary dramatically between the two seasons. Seaweed cultivation is greatly influenced by seasonal variability in wind patterns and rainfall (Neish, 2013). The effective cultivation of seaweed is generally performed in the wet season, when the average cultivation growth is 3% per day. From October to March, seaweed growth is about 2% or sometimes it does not grow optimally because the water is too warm. The other major cause of yields uncertainty is disease, such as *ice-ice,* a common disease of *E.Cottonii*.

S.4 Low quality of raw dried seaweed

Supports from government, from both national and local levels, have helped farmers meet target volume of raw dried seaweed. Seaweed farming has provided a significantly high production. However, poor quality in the purchased products or services is a significant risk and can have a domino effect through the supply chain and eventually reaching the final customer (Zsidisin et al., 2000).

A major cause of low quality of raw dried seaweed stems from the fact that farmers do not understand or take part in good seaweed cultivation and post-harvest activities. Low quality seedlings, disease and environmental disturbances also contribute to low quality yields.

In seaweed cultivation, maintenance and harvesting are the critical aspects that influence the quality of raw dried seaweed. Maintenance activities are generally quite simple, yet many farmers do not pay serious attention to these practices. As a result, carrageenan or agar content in seaweed becomes lower than standard requirements. In addition, the farmers often harvest seaweed too early, before 45 days. The critical process of post-harvest activity is drying. Good drying practices would result in better quality seaweed. However, some farmers conduct drying seaweed on sand or dirt to increase weight.

Seaweed seeds are mainly taken from vegetative propagation which the seeds are used frequently. Repeating this method decreases genetic diversity, reduces both content and quality of carrageenan and agar, and increases the vulnerability to disease (Hurtado & Cheney, 2003).

Environmental circumstances such as light, temperature, water quality, and water motion also influence seaweed quality. For *E. cottonii*, *ice-ice* disease is a highly problematic. The disease reduces both the content and quality of carrageenan and agar.

The effects of low quality of raw dried seaweed can damage the production machinery and reduce the product’s quality. Low quality of raw dried seaweed is not only detrimental to focal firms, but also for seaweed suppliers. Excess stocks of raw dried seaweed are one common problem particularly in the upstream side. The price of raw dried seaweed on average was lower 50% than usual, on average. An abundance of low quality seaweed can lead to the use of raw dried seaweed as a raw material for lower price animal and fish feed. Consequently, carrageenan or agar companies try to find other seaweed suppliers who can meet the standard, even though the price maybe higher.

S.5 Delivery failure of raw dried seaweed

As an archipelagic country, trading of raw dried seaweed from seaweed suppliers to focal companies in Indonesia depends primarily on sea transport. The largest maritime ports are Makassar port in the eastern part and Jakarta's Tanjung Priok in the western part. However, the ports' infrastructures were under repair, resulting in very long queues, with some containers waiting in line for six or seven days. Furthermore, the low capacity of the ports causes the process of clearing goods in the ports to take a long time. High transportation costs in domestic shipping are another reason for supply delivery failure. Consequently, these problems further disturb the logistics schedule.

S.6 Distance between seaweed suppliers and focal companies is far

As previously mentioned, many seaweed farmers are located in the eastern part of Indonesia, whereas carrageenan and agar producers are found in the western part. Seaweed grows very well in the eastern part of Indonesia because the environment is suitable for producing high quality seaweed. However, cultivation locations cannot be easily reached because they are located in remote areas and/or on small islands that are separated by the sea or the bays.

Investors chose the western part of Indonesia to build carrageenan or agar companies. In these regions, infrastructure elements such as electricity, roads, and communication networks are better than in the eastern regions.

Therefore, there is a significant delay for the delivery of raw materials. Another effect related to these distances is that moisture content above 35% may lead to product deterioration over the course of transport. The factors disrupt production continuity.

Table 4-4 shows the risk sources, causes and effects of supply risks in a seaweed supply chain.

Table 4-4 : Supply risk sources with their causes and effects

No.	Risk source	Causes	Effects
S.1	Fluctuation of raw dried seaweed price	• No standard price mechanism • Increasing global demand • Quality of raw dried seaweed	• Fluctuations of cash flow
S.2	Scarcity of raw dried seaweed	• Lack of farmers' capital • Growing global demand • Limited availability of good seedlings	• Disturbance of flow materials in a seaweed supply chain
S.3	Uncertain of seaweed yields	• Seasonal variability • Disease present in harvested product	• Disturbance to production
S.4	Low quality of raw dried seaweed	• Farmers do not understand Good Aquaculture Practices (GAP) • Low quality seedlings • Disease • Environmental disturbances	• Detriment to equipment and production machinery • Low quality products • Excess stock in seaweed suppliers
S.5	Failure in raw dried seaweed delivery	• Dwell- time in the ports • Low capacity of the ports • High transportation costs of domestic shipping	Disturbance of the production schedule
S.6	Distance between seaweed farming and the companies is far	• Seaweed cultivation is concentrated in the eastern regions of Indonesia • Carrageenan and agar firms are concentrated in the western regions	High transportation costs

4.4.2.2 *Demand risk*

Demand risk can originate from the uncertainty of customer demand, product price fluctuations, and consumer switch to other producers.

D.1 Demand uncertainty

Currently, around six million tons of fresh algae are cultivated annually throughout Asian countries, amounting to approximately 90% of the commercial demands (Besada et al., 2009). Global demand of carrageenan has increased by 25% on average between 2010 and 2013. On the other hand, the export volume of agar has declined on average by 13% during these years.

Many factors drive demand volatility covering global competition and supply fluctuations. The main competitors of the carrageenan industry are China and the Philippines. The three largest carrageenan producers in the world are in China, with an average of 2,000 to 4,500 tons of carrageenan annually. There are 14 carrageenan companies in Shandong Province, Fujian Province, Guandong Province and Hainan Province with capacities on average of 500 to 1,000 tons annually (Cybercolloids, 2012). The Philippines contributes 46% to the total carrageenan global production (Panlibuton et al., 2007). According to Hurtado (2013), there are 12 semi-refined carrageenan and 3 refined carrageenan companies. The main competitors of agar producers are the manufacturers in Chile and Japan. Fluctuation of raw dried seaweed availability is also caused by seasonal changes during seaweed cultivation. Excess or insufficient capacity of the products is one of the impacts. In addition, companies also face cash flow disturbances.

D.2 Products price volatility

The competitive market determines the price of carrageenan and agar. Most of the carrageenan companies set the price in accordance with the global price. The major market players of carrageenan are Chinese companies. On the other hand, the price of agar is mostly influenced by domestic market because approximately 80% of agar is distributed in the national market. Another reason for price volatility is product quality, with higher quality products bringing higher prices. Most buyers purchase carrageenan and agar due to particle size, solution viscosity, powder color, and the pH value.

Price fluctuations become vulnerable to financial flows of the key actors in a supply chain. Uncertain prices in seaweed suppliers significantly influence the profitability of focal companies and upstream members of the supply chain.

D.3 Customers switching

Since customers are a very valuable part of the supply chain, companies have made efforts to satisfy their requirements. On the other hand, satisfaction does not guarantee that customers will continuously remain with one company (Jones & Sasser, 1995). A main reason that customers are switching is related to price and quality, as well as concerns with delayed product delivery. Switching behavior among customers influences the profitability and market share of a company.

Risk sources, their causes and their effects are shown in Table 4-5.

Table 4- 5: Demand risk sources with their causes and effects

No.	Risk source	Causes	Effects
D.1	Demand uncertainty	• Global competition • Upstream supply fluctuations	Excess or insufficient capacity Disturbances in cash flow
D.2	Product price volatility	• Carrageenan companies as a competitors abroad, were decreasing the price • An increase of raw dried seaweed price	Disturbances in cash flow of a supply chain
D.3	Customer switching	• Price and quality did not meet buyer requirements • Delay of products delivery	Decreasing profitability and market share

4.4.3 External Risks

External risks stem from variability in government regulation, exchange rate volatility, road infrastructure in relatively bad condition, poor quality of electric supply, scarcity of fresh water, and energy supply disturbances.

4.4.3.1 *Policy, Finance, and Infrastructure*

This type of risk stems from variability in government regulations, exchange rate volatilities, and poor infrastructures related to roads, power supply electricity, and fresh water.

E.1 Variability of government regulation

Variability of government regulation is one source of policy risk that refers to the frequency of changes in the law and policy in the seaweed industry. According to Wagner & Bode (2008), authorities play an essential role in building and implementing a supply chain in dynamic conditions. There are still different views among the related ministries, such as Ministry of Marine Affairs and Fisheries and the Ministry of Industry as to the best method for developing the seaweed industry in Indonesia. Government policies such as tax incentives frequently change according to the regulations implemented by new governments. Consequently, carrageenan and agar companies are hardly able to fully adapt with the new regulations or legal aspects before they are changed again.

E.2 Exchange rate volatility

Financial risk refers to exchange rate volatility, particularly with respect to the Indonesian Rupiah rates (IDR) to the US Dollar (USD). Most of companies import chemical materials such as potassium hydroxide. The majority of the carrageenan companies export on average 80% of their product, thus exposing the industry to exchange rate volatility. This condition adversely affects production continuity and its total cost. Some supporting materials are imported which companies could not buy in higher price. Therefore, it disrupts the production. Factors influencing the exchange rate are monetary policies, interest rates, and political stability.

E.3 Poor infrastructures

According to the OECD (2011), the limited quantity and poor quality of the transport infrastructure in Indonesia results in major problems for the economic development of the nation. On the other hand, the number of vehicles has increased about threefold during the period between 2001 and 2010. Road infrastructures in eastern Indonesia are of lower quality than in western Indonesia. Seaweed farmers are located in remote areas, especially in eastern Indonesia where the roads are in bad condition.

These poor conditions influence the distribution from farmers to local traders and then to large traders, thus requiring more time. Afterwards, the large traders deliver the raw dried seaweed to focal companies in delayed time.

E.4 Poor power quality of electricity supply

Electric power quality is 'a term that refers to maintaining the near sinusoidal waveform of power distributions, both voltages and currents at rated magnitude and frequency' (Chattopadhyay et al., 2011). Long interruptions in the electricity supply lead to damaged machinery and tools, causing major problems for carrageenan and agar companies, particularly with respect to their production and financial performance. The interruptions may cause a low capacity of the power grid, disturbances on the power grid and a short circuit.

E.5 Scarcity of fresh water

Fresh water is a requirement in the seaweed supply chain, in terms of both quantity and quality since it is used for food processing. Processing of carrageenan and agar requires a large amount of fresh water, since each process requires some amount of water. The other critical element in the production is ensuring fresh water that is free from hazardous contaminants. Access to clean water presents a problem because the stock of water is decreasing. According to Kirby et al., (2003), there is a great demand for fresh water for a variety of purposes, namely food processing, domestic uses, industries, tourism and leisure, energy production, navigation, and ecosystem maintenance. With respect to seaweed production, the process is interrupted without sufficient sources of fresh water. Furthermore, the quality of the water needs to be considered, because contaminated water can be a potential media for pathogens in the food chain.

4.4.3.2 *Social Risks*

Bekefi,et al. (2006) define social risk as 'challenges by stakeholders to companies' business practices due to real or perceived business impacts on a broad range of issues related to human welfare, for example working conditions, environmental quality, health, or economic opportunity'. In this study, social risk was categorized into two groups: low acceptability from local people and low possibility of the surrounding community to work in a carrageenan or agar company.

E.6 Low community acceptance

A neighborhood is affected by the companies' activities either directly or indirectly. It is important to take into account the acceptability of a company's operations for long-term business sustainability. Low acceptability from local people is typically due to lack of information on the products and the operations utilization to the local community. The other cause is that local people are not involved in the planning process of building a plant. In addition, liquid waste from seaweed production has a bad odor which also influences the community to protest operations. These factors may cause protests from local people, leading to a disturbance in production continuity.

E.7 Lack of employment opportunities

Limited opportunities for local neighborhoods for employment are caused by the people having limited educational backgrounds and their skills did not meet with company requirements. Some companies provide career opportunities, but only in limited positions such as laborers on the production line. Consequently, these factors may lead to increasing unemployment in surrounding areas and the growth of the local economy is likely to experience a gradual decline.

4.4.3.3 *Environmental risks*

E.8 Industrial seaweed wastewater negatively impacts to the environment

Production of carrageenan and agar uses alkaline solutions which may cause harm to the environment. These alkali treatments and extraction processes also lead to large quantities of wastewater. There is limited availability on data regarding the exact amount of wastewater resulting from the carrageenan and agar industry. Poor wastewater management in the seaweed industry and irregular monitoring and evaluation by the government the primary reasons that wastewater has negatively impacted environment. The negative effects of wastewater are a bad smell surrounding the factory, water pollution to rivers, and protesting from local neighborhoods to close the plant.

E.9 Solid seaweed waste negatively impacts the environment

Solid waste from the carrageenan and agar industry refers to solid residues from the extraction process which may contain hazardous materials. Large amounts of solid seaweed waste could be introduce potential pollutants to the environment. Furthermore, the community surrounding the plant may demonstrate in order to encourage a company properly dispose of the waste. Monitoring and evaluation of waste is rarely conducted by the government, there is a lack of good waste treatment and poor research and development efforts connected to seaweed biomass; these factors are reasons behind potential harm to the environment resulting from solid seaweed waste.

E.10 Natural disasters: floods and earthquakes

Catastrophic events such as floods and earthquakes create great vulnerability for a company and its potential to operate in the future. Although natural disruptions are infrequent events, they can have a very harmful and lasting impact on a supply chain. Flood in Thailand in 2011 is an example that demonstrates how many companies can lose a large amount of profit and consumers due to natural hazards (Leon, 2014). If they could not recover in a short time, companies face losses that may require the closure of their operations. Floods can be the result of either natural or man-made factors, whereas earthquakes are caused by natural factors. Continuous heavy rain can cause dams to fail.

Table 4-6: External risk sources with their causes and effects

No.	Risk source	Causes	Effects
Finance, policy and infrastructure risks			
E.1	Variability of government regulation	Different views from the related ministries to develop the seaweed industry	Companies have difficulty adapting to new regulations or legal aspects
E.2	Fluctuation of currency exchange rates	• Monetary policy • Interest rate • Political stability	• Interrupted production • Disturbance on financial performance
E.3	Poor infrastructure	• Large gap between number of roads and number of vehicles • Government not really focus on road construction, especially in remote areas	Delay of raw materials delivery
E.4	Disturbance of electricity supply	• Low capacity of power grids • Disturbances of power grids • Short circuits	Interrupted production
E.5	Scarcity of fresh water	High demand for freshwater for many purposes	• Interrupted production • Water can be a media for pathogens in a food supply chain
Social risks			
E.7	Low community acceptance	• Lack of information on products and their usefulness for the community • Local people are not involved in planning process • Bad odors of liquid waste from seaweed productions	Protests from local people
E.8	Lack of employment opportunities	The educational background and skills do not match companies requirements	• Increasing unemployment surrounding the company • Stagnancy of local economy
Environmental risks			
E.9	Industrial seaweed wastewater negatively impacts the environment	• Poor wastewater treatment • Irregular monitoring and evaluation by the government	• Bad odors surrounding the seaweed plant • Protests from the local community
E.10	Seaweed solid wastes negatively impacts the environment	• Poor solid waste treatment • Poor research and development connected to seaweed biomass • Irregular monitoring and evaluation by the government	
E.11	Natural disasters: floods and earthquakes	• Floods resulting from natural and manmade factors • Earthquakes resulting from natural factors	Shut down of operations

In general, the impacts of seaweed supply chain risks can be divided into three types of consequences, primarily economic, environmental, and social impacts. Economic impacts are related to the loss of production related to quality problems, interrupted production, loss of customers, loss of profit, and stagnancy in the local economy. Environmental impacts include disturbances to locals with regards to solid and liquid waste from carrageenan and agar productions. Social impacts cover unemployment and protests from the surrounding community. In terms of duration, these impacts can be categorized as either short term, medium term, or long term.

4.5 Assessment of Seaweed Supply Chain Risks

The third objective in this research was assesing risk within seaweed supply chain. Risk assessment is a critical step in managing supply chain risks, these assessments have four purposes. First, risk assessment can help decision makers allocate resources and prioritize different risk mitigation strategies. Second, the assessment supports management to focus on essential risks. Third, the assessment can be used as a program to meet legal or regulatory requirements. Finally, risk assessment is also used to develop contingency plans (Sodhi & Tang, 2012).

The method of risk assessment can be categorized into three distinguishable methods: qualitative, semi-quantitative, and quantitative risk assessment. The qualitative method is the simplest and quickest; however it can be rather subjective. Qualitative risk assessment is used when data are not sufficient to make numerical estimates. The semi-quantitative assessment includes both a numerical outlook due to its combination of quantitative and qualitative usage of data. Quantitative risk methods provide numerical data which can predict the likelihood of risks in the future. Some considerations to choose a risk assessment method include availability of data, financial resources and the available time. In this research, risk assessment was conducted by the semi-quantitative method which allows expert judgment.

Risk assessment is typically carried out by risk mapping for every identified risk. A risk map or a risk matrix shows two aspects of risk events: the likelihood or frequency of an event, and the impact of an incident. The probability or likelihood of an event is due to exposure to risk and is partly based on the likelihood of a trigger that leads to the realization of the risk. Consequences may be estimated reasonably accurately if there regulations or laws are in existences that define compliance in terms of quantitative and qualitative aspects (Mitchell, 1995). There are two main questions involved in risk assessment: how probable or likely an adverse event will happen, and what are the consequences from that event? (Harland et al., 2003).

Calculating the probability of an adverse event is a fundamental aspect of assessing the risk and using statistical databases as a requirement (White, 1995). The nature of probability distributions of risk (normal, skewed left or right) is important to understand so the historical data is needed to draw the risk assessment. However, carrageenan and agar companies do not have the historical data to describe the probability distribution. Therefore, in the absence of adequate data, the assignment of probabilities is a subjective process that relies on the experts.

In this research, an in-depth analysis of risk assessment was carried out by interviewing carrageenan and agar companies. The respondents were asked to recall and estimate frequency of an adverse event. Afterwards, the respondents were asked about the potential impacts of an incident.

The risk sources of a seaweed supply chain are depicted in a risk map which illustrates probabilities and impact using a Likert scale. A seven-point Likert scale was used to operationalize the risk sources (see Table 4-7).

Table 4-7: The frequency and impacts of risk sources using Likert scale (7 points)

Scale	Likelihood of an adverse event	Scale	Impact
1	Never	1	Not relevant or never
2	Rarely, the probability is about 10%	2	Not significant
3	Occasionally, the probability is about 30%	3	Somewhat insignificant
4	Sometimes, the probability is about 50%	4	Neither significant or insignificant
5	Frequently, the probability is about 70%	5	Somewhat significant
6	Usually, the probability is about 90%	6	Significant
7	Every time	7	Very significant

Adapted from Sodhi and Tang (2012)

Afterwards, the risk intensity or the importance rating was categorized based on the value of the response (Sodhi & Tang, 2012). In relative terms, risk intensity is indicated by a risk score value multiplying its frequency and impact. The value is classified into five categories: negligible (the value 1-10), marginal (the value 11-20), critical (the value 21-30), most critical (the value 31-40), and catastrophic (the value 41-49). These categories are adapted from Tummala and Schoenherr (2011) who divided the classification of risk exposure values. Risk assessments for carrageenan and agar supply chains are explained further in the following sections.

4.5.1 Assessment of Carrageenan Supply Chains

Risk assessment of carrageenan supply chain was conducted by an in-depth interview to 8 companies in April 2013. The companies are located in the province of South Sulawesi (2 companies), East Java (2 companies), West Java (2 companies), Banten (1 company), and West Nusa Tenggara (1 company) (see Table 4-1). The respondents consisted of directors (37.5%), production and quality managers (37.5%), and marketing managers (25%). Most of the interviewed companies produce semi-refined carrageenan which have total asset more than IDR 10 billion. An in-depth interview was guided by a questionnaire, which a respondent should mark to the scale of probability and impacts of a risk source (see Appendix). The questionnaire sent in advance by e-mail prior to the face-to-face interview. Therefore, the respondents could understand contents of the questionnaire. The interview was taken on average two hours.

A risk matrix depicting the frequency and impact of the risk sources in carrageenan is shown in Figure 4-4. In the following depiction, Figure 4-5, the Pareto chart describes the risk ranking of a carrageenan supply chain.

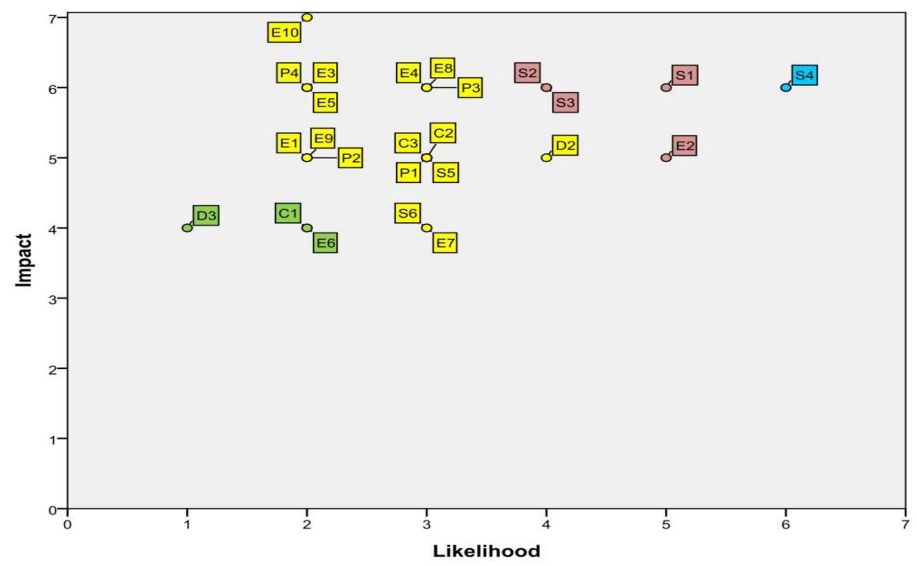


Figure 4-4: A risk matrix of carrageenan supply chains

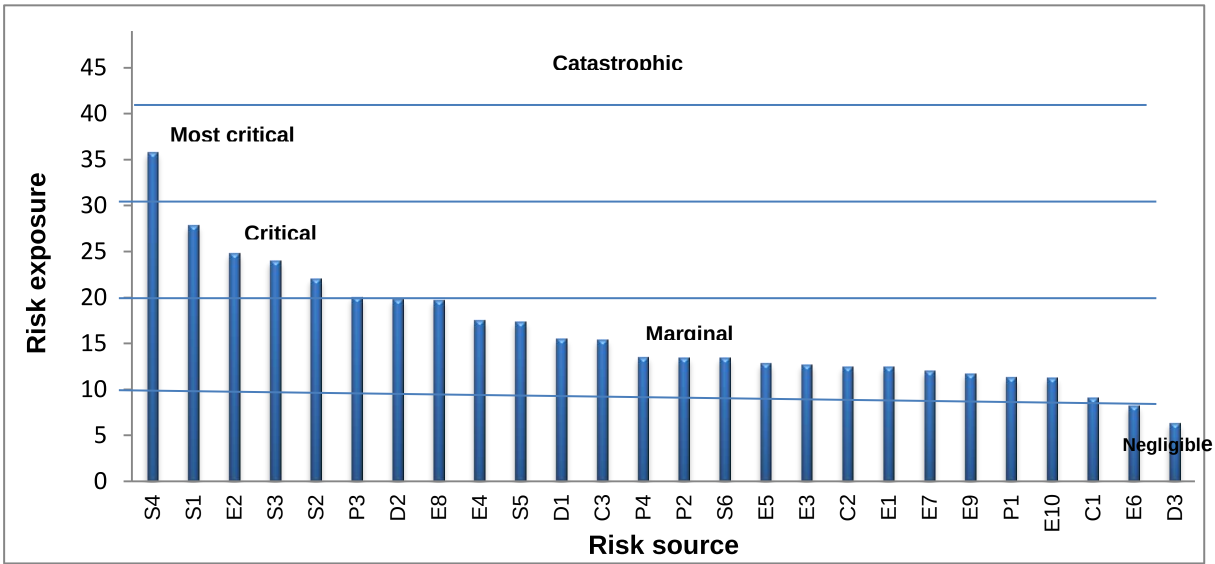


Figure 4-5: A pareto chart of risk sources in a carrageenan supply chain

Refer to the Figure 4-4, the risk matrix shows that the most critical risk in a carrageenan supply chain is poor quality of raw dried seaweed (S4). This finding may be explained by the fact that carrageenan companies often complain that they received raw dried seaweed that did not comply with the standard requirement, such as product having a moisture content of more than 35%. Consequently, the carrageenan and agar companies buy the RDS at a low price because the company will invest more in cleaning of the seaweed, as well as further drying applications to reach a moisture content of 30-32%.

The quality standard for seaweed supply chains comprises standardization rules for the farmers and for the carrageenan or agar production (Neish & Julianto, 2008). The standard protocols for seaweed cultivation cover the following: Euro Retailer Produce Working Group (EUREPGAP) on standards and procedures for the development of good aquaculture practices (GAPs) in conventional agriculture (general regulations, control points, and compliance criteria for integrated aquaculture assurance), and FAO Guidelines for Aquaculture Certification; quarantine protocols for tropical seaweeds such as those proposed by Sulu et al. (2004).

Seaweed farmers are often unconcerned with the importance of the raw dried seaweed quality. There is a tendency for seaweed farmers to only consider their potential profit, while failing to focus on quality standards. These farmers frequently harvest their seaweed at 30 days on average, whereas good quality seaweed is harvested between 40 and 45 days. If the seaweed is harvested earlier than it should be, carrageenan content and gel strength is lower.

The main factor affecting the quality of raw dried seaweed is in the drying activities. Drying activities are often not considered by farmers as a critical factor in achieving high quality yields. The majority of farmers dry their seaweed on the sand without using a protection pad, and thus, the seaweed is mixed with sand and other materials.

The other main cause of poor quality is lack of seaweed quality maintenance which often leads to disease, particularly *ice-ice*. This disease appears commonly in *E. cottonii* types and causes whitened segments in nearly all of the seaweed branches. The disease often appears during seasonal changes from the dry to the wet season, as well as during the rainy season. The disease could be triggered by extreme changes in salinity, temperature, light intensity and high incidents of ephyphit (bacterial pathogens). Wound injuries such as those caused by fish or mechanical damage due to water movement of healthy plants can be possible sites of entry for bacteria (Largo et al., 1995). Mendoza et al. (2002) showed that ice-ice leads to the decrease of carrageenan yield, viscosity and gel strength of infected thalli. Ice-ice disease also leads to a significant decrease in seaweed output, as well as in carrageenan yield (25-40% decrease) compared to the healthy crop. The period from May to August is when a higher incidence of ice-ice can be documented.

The quality of seaweed is also influenced by environmental conditions such as water availability and quality during cultivation (as explained in Chapter 2). Seaweed farmers should pay close attention to water quality, climate and the geography of seabed.

A primary risk faced by seaweed farmers is the seasonal changes between the dry and wet seasons. Most farmers solve the problem by having more than one cultivation site and through seasonal shifting of the sites. Farmers can change the seaweed type when one variety does not grow very well, such as cultivating *E.spinosum* when *E.cottonii* did not grow well in the previous season.

Other important findings that are categorized as critical risks in the carrageenan supply chain are fluctuations of currency exchange rates (E2), scarcity of raw dried seaweed (S2), and uncertainty of seaweed yields (S3). Fluctuation of currency exchange rates is typically beyond the control of carrageenan companies because it is influenced by the global economy.

The continuous growth of product development of carrageenan affects the increasing demand of raw dried seaweed. On the other hand, supply of raw dried seaweed for *E.cottonii* faces problems related to seasonal change, disease and lack of capital available to farmers. These conditions lead to scarcity of raw dried seaweed for the *E.cottonii* variety. Threat of scarcity puts pressure on the financial performance in the short-run, while long term scarcity concerns could lead to a decline in the growth of a company.

Volatile raw material prices are influenced by fluctuations in foreign demand which often change rapidly. Scarce amounts of raw dried seaweed lead to higher prices, leading to focal companies buying greater quantities of raw dried seaweed at a lower price, when available. In the event that raw dried seaweed is scarce, local traders or large traders may buy at a higher price, even though the quality does not meet their requirements, in order to ensure some level of inventory. In the long term, this will cause a company to face financial loss. The price of raw materials is a major component in a company's cash flow.

Over half of the risks that are categorized as marginal risks are machine breakdowns (P3), uncertain product price (D2), liquid waste negatively impacting the surrounding environment (E9), great distances between seaweed cultivation sites and producing company (S6), poor quality of carrageenan products (P4), inappropriate production scheduling (C2), lack of collaborative planning between focal companies and seaweed farmers (C3), delivery failure of raw dried seaweed (S5), demand volatility (D1), tax and legal regulations that do not support the development of the seaweed industry (regulatory variability (E1), disturbances to the electricity supply (E4), natural disasters: flood and earthquakes (E11), low product yields (P2), consumers switching to other carrageenan companies (D4), poor infrastructure between seaweed farmers and local and large traders (E3), disturbances to the water supply (E5) and low possibility to work in carrageenan manufacturing (E8).

Negligible risks are related to failures in chemical mixing (P1), the environmental impact of solid waste (E10), inadequate safety stocks (C1), and low acceptance from the community (E7). These findings have important implications for developing effective mitigation strategies

4.5.2 Assessment of Agar Supply Chains

To assess agar supply chain risk, the risk matrix was used. Figure 4-6 shows the risk matrix of the agar supply chain, it can also be noted that supply risk is a critical risk in the chain. These results are consistent with those of other studies that suggest that supply risk is the most critical risk in the supply chain. Wagner and Bode (2008) stated that supply side risks have a significantly negative impact on supply chain performance. On the other hand, the regulatory, legal and bureaucratic risks, infrastructure risks and catastrophic risks did not significantly affect the supply chain performance.

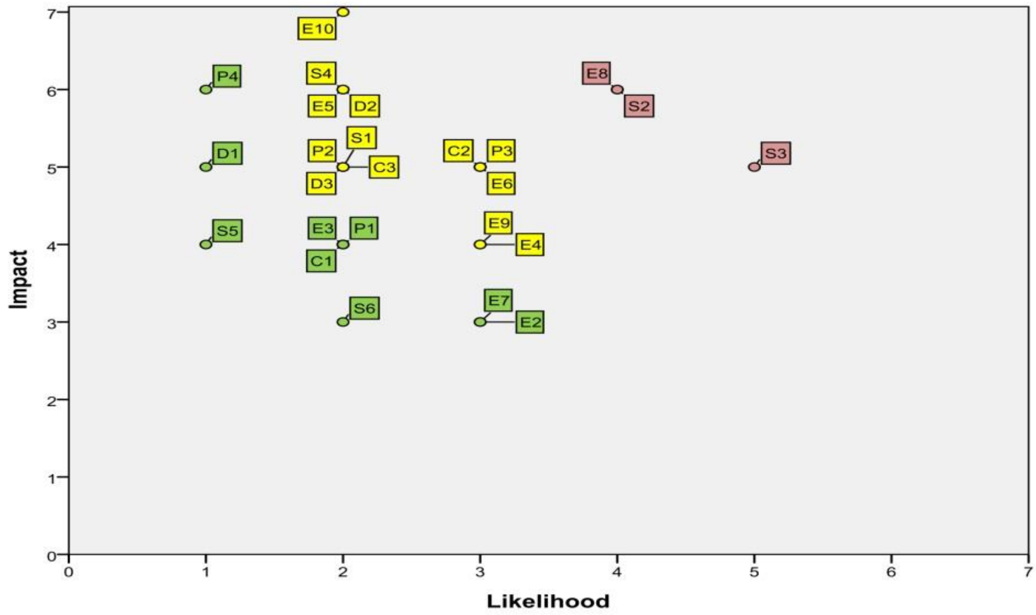


Figure 4-6: A risk matrix of agar supply chain

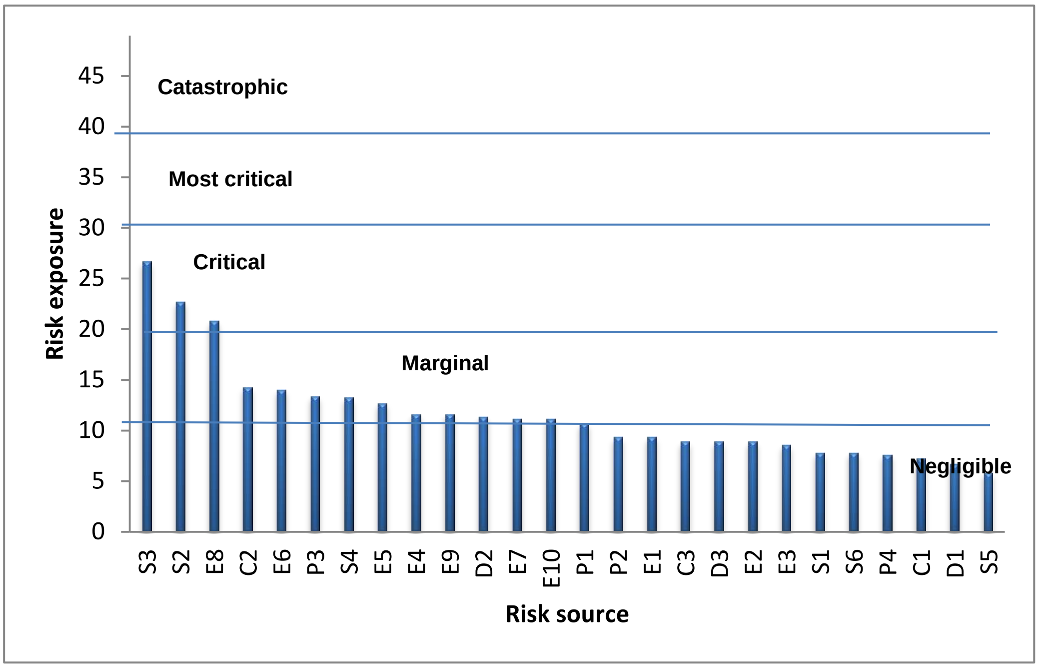


Figure 4-7: A pareto chart of agar supply chain risks

The critical risks in the agar supply chain are uncertainty of seaweed yields (S3) and scarcity of *Gracilaria* (S2), as well as the negative impact of waste water on the environment (E8). Other risks are categorized as marginal and negligible risks.

Previous studies have noted the importance of quality risk management in the food sector. These results correspond with the theory that quality risk is one of the major risks in the food sector. As stated, even a negligible risk from one element in a supply chain could negatively affect other aspects of the supply chain (Giunipero & Eltantawy, 2004).

Food safety risk management in a supply chain is a crucial aspect for a company because it affects financial flow, as well as consumer health and safety (Chavez & Seow, 2012). However, very little information was found in the literature with respect to the effects of quality in supply chain risk. Food quality risk in the supply chain has gained interest in recent years, with the concepts of quality, risk and supply chain undergoing more in-depth investigations (Chavez & Seow, 2012).

It is necessary to establish adequate food safety management approaches through regulation and control in order to minimize microbiological, chemical, and physical hazards that may enter the food chain. Proper management is necessary to prevent and minimize the effects of risks along seaweed supply chains. With regards to the upstream side of the supply chain, this requires Good Aquaculture Practices (GAP), while in the production process the principles of Hazard Analysis and Critical Control Point (HACCP) are utilized.

Important regulatory documents with relevance to food safety management include: the European Union (Member Organization): European Union standards for E407a (Processed *Eucheuma* Seaweed) and E407 (Carrageenan); JECFA – FAO/World Health Organization: standards for Processed *Eucheuma* Seaweed and Carrageenan; Codex FAO; USFDA; Hazard Analytical Control Points requirements (HACCP),; ISO 9001: 2000, Quality Management System; ISO 14001: 2004, Environmental Management System; ISO 22000: 2005, Food Safety Management.

5 Mitigation Strategies of Seaweed Supply Chain Risk

Mitigation strategies are intended to decrease the likelihood and the impact of risks. These strategies should help a supply chain to manage risks under normal conditions, as well as abnormal circumstances or major disruptions. Therefore, a supply chain with robust risk mitigation strategies would become more resilient (Tang, 2006). Decision makers should consider two essential aspects of robust mitigation strategies: First, strategies should help a company to minimize costs and increase customer satisfaction in regular circumstances. Second, the strategies should assist a company in sustaining its operation during and after major disturbances (Sodhi & Tang, 2012a; Tang, C., 2006).

According to Kleindorfer and Saad (2005), risk mitigations of a supply chain must utilize methods which fit with the specific characteristics and requirements of decision conditions because no definitive strategy fits all circumstances. The key element of supply chain risk mitigation is “end-to-end” visibility, which requires high quality information in order to improve supply chain confidence (Christopher & Lee, 2004).

In the next section, existing research studies on risk mitigation strategies are described. The following section defines a suitable model of risk mitigation strategies within a seaweed supply chain using the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) from multi-criteria decision analysis (MCDA). Finally, in the last section, PROMETHEE is applied to assess risk mitigation strategies for a seaweed supply chain.

5.1 Previous Studies of Mitigating Risks within a Supply Chain

A rich body of literatures on risk mitigation strategies in supply chains exists. Most of the papers offered different mitigation strategies which are intended to minimize supply chain risks as a general concept, while only a few studies offer guidance against specific risks. Some papers, however, are focused on how response company should respond to supply and demand risks (Demirel, 2012; Mitchell, 1995; Tomlin, 2006; Wang et al., 2010; Zsidisin et al., 2004; Zsidisin et al., 2000). Flexible strategies are most commonly discussed by scholars as a way to mitigate risks in industrial supply chains. Some researchers also incorporate a decision model to determine the most appropriate method for mitigating supply chain risks.

Mitchell (1995) suggested mitigating supply risks through choosing a leading company, using an approved list of suppliers, multiple sourcing of suppliers, visiting supplier operations and establishing good communications with suppliers. Lee (2004) created the principles of Triple A (Agility, Adaptability and Alignment) for mitigating supply chain risks. Agility enables a company to rapidly respond to supply, demand, and external risks. A supply chain should be designed in a way that it is adaptive to market dynamics, product development, and new technologies. Alignment of supply chain members’ interests is also very important to minimize supply chain risks.

Rice and Caniato (2003) developed and categorized resilience strategies into five groups: supply, transportation, production facilities, communications, and human resource strategies. They also classified firms' responses into four levels: basic, reactive, proactive, and advanced initiatives.

The other view of risk mitigation strategies are classified into four general strategies: prevention, response, protection, and recovery strategies. Prevention strategies are related to forecasting and risk reduction. Risk detection and speed strategies are types of response strategies. Protection strategies include mitigation in inventory, capacity, information, and network structure. Recovery strategies can be implemented through maintenance of customer loyalty and buying business continuity insurance (Hopp et al., 2012).

Other mitigation strategies of supply chain risks, according to Sodhi and Tang (2012) are alignment of supply chain partners' incentives, building buffers and flexibility. Alignment strategies are mechanisms that help to coordinate supply chain members in order to minimize behavioral risks within the supply chain. These alignment strategies refer to supply contracts covering wholesale price contracts, buyback contracts, and revenue sharing contracts. A company establishes reserves, such as extra inventory, extra back-up production capacity and extra back-up suppliers, throughout the supply chain to decrease the likelihood of encountering risk. Flexibility strategies consist of multiple suppliers, flexible supply contracts, flexible manufacturing processes, postponement of product, and responsive pricing (Sodhi & Tang, 2012).

Tang and Tomlin (2008a) explained a framework, as well as thorough discussion, for various flexibility strategies based on their risk source classifications: supply, process and demand risk. Furthermore, Tang and Tomlin (2009b) reviewed flexibility strategies as preventive measures for minimizing adverse effects of supply chains. The flexible supply strategies are comprised of multiple suppliers and flexible supply contracts. Companies can deploy flexible manufacturing processes to further mitigate process risks. Flexible demand strategies cover both postponement and responsive pricing.

Elkins et al. (2005) developed 18 practices for mitigating risk in a supply chain; these practices are further divided into four main strategies, according to organizational functions. The key organizational areas cover strategic sourcing and advanced procurement, supply-base management, supply chain operations management, and strategic supply chain design.

Stecke and Kumar (2009) provided a variety of strategies that can be implemented in the case of different natural and man-made catastrophes. These strategies are comprised of proactive, advanced-warning, and cost/benefit trade-off strategies. Craighead et al. (2007) proposed two supply chain risk mitigation strategies which consist of a firms capability for recovering from disruptions, as well as its required ability for building risk awareness.

In terms of utilizing the decision model in risk mitigations, Faisal et al. (2006) designed an Interpretive Structural Model (ISM) to identify and assess the enablers of risk mitigation of Small Medium Enterprise (SME) manufacturing supply chains in India. Wang (2014) integrated the concept of a fuzzy risk approach and fuzzy Delphi to select the appropriate supply chain risk mitigation strategy. A recent study by Talluri et al., (2013) evaluated and proposed combining an empirically grounded simulation methodology with Data Envelopment Analysis (DEA) and a non-parametric statistical method to determine the most appropriate mitigation strategies in a supply chain in terms of efficiency. They found that the more efficient strategies are focused on flexibility strategies rather than on redundancy strategies.

Wang et al. (2010) proposed a model which is comprised of a combination between process improvement and dual sourcing strategies in an effort to manage suppliers' reliability. Demirel (2012) developed a game-theoretical model to compare single and dual-sourcing strategies, which considers supply variability across multiple channels.

It is noteworthy that risk mitigation strategies should be assessed in a comprehensive way. Talluri et al. (2013) recommended assessing the mitigation strategies through considering aspects of sustainability. Few studies analyze aspects of sustainability; therefore, the concept of sustainable development should be taken into consideration for risk mitigation in a seaweed supply chain.

5.2 Sustainable Development

The concept of sustainable development was initially recognized during the international policy debate by the World Conservation Strategy in 1980. The concept of sustainable development, however, had been gaining relevance since 1972, when the United Nations (UN) held the 'Conference of the Human Environment' in Stockholm, Sweden and discussed the relationship between quality of life and environmental quality. The term 'sustainable development' was popularized in *Our Common Future,* a report published by The Brundlandt Commission, the World Commission on Environment and Development (WCED). Sustainable development is defined as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (World Commission on Environment and Development, 1987, p.43). The report was used as a foundation for the 1992 Earth Summit in Rio de Janeiro, Brazil, which introduced the Rio Declaration in Environment and Development, as well as Agenda 21, a global plan of action for sustainable development.

The triple bottom line of sustainable development is comprised of economic development, social equity, and environmental protection. Integrated decision making for the three pillars is required, and therefore, decision makers should be capable of balancing the economic and social needs of the community, as well as aim for environmental conservation (Rogers et al., 2008). Furthermore, sustainable development should be viewed as a continuous interaction between the three pillars (Barbier 1987). Sustainable development can be achieved if decisions are made to be economically profitable, biologically appropriate and socially acceptable (Eigner-Thiel et al., 2013).

The requirement for the sustainable development of fisheries, in particular, is embedded in both the United Nations Convention on the Law of the Sea (UNCLOS) and the United Nations Conference on Environment and Development (UNCED). The UNCLOS, developed in 1982, established a legal framework for the management of marine resources (United Nations Convention on the Law of the Sea, 10 December/1982). Agenda 21 considers the importance of oceans and coasts in the global-life support system, along with presenting positive opportunities for sustainable development in Chapter 17. Program areas of Chapter 17 are divided into seven major sectors: (a) integrated management and sustainable development of coastal and marine areas, including Exclusive Economic Zones, (b) marine environmental protection, (c) sustainable use and conservation of living marine resources of the high seas, (d) sustainable use and conservation of living marine resources under national jurisdiction, (e) addressing critical uncertainties for the management of marine environments and climate change, (f) strengthening international, as well as regional, cooperation and coordination, and (g) sustainable development of small islands (UNCED, 1993). Chapter 17 is the longest chapter of Agenda 21 consisting of 42 pages and includes one of the most complex discussions surrounding the topic of sustainable development (Cicin-Sain, 1993).

Following these initiations, the FAO formulated a global Code of Conduct for Responsible Fisheries in 1995. This code established principles and international standards of behavior for responsible practices with an objective of ensuring the effective conservation, management and development of all fisheries, with due to respect for the ecosystem and biodiversity (Food and Agriculture Organization of the United Nations, 1995).

Furthermore, the FAO developed several operational guidelines for the sustainable development of marine capture fisheries in collaboration with the Australian Department of Agriculture, Fisheries and Forestry in 1999. These guidelines provide the sustainability indicators, especially for marine capture fisheries, which are comprised of four main dimensions: ecological, social, economic and governance/institutional criteria in which the fishery operates (Potts, 2006). Garcia et al. (2000) made a hybrid framework combining the FAO definition with the FAO Code of Conduct for Responsible Fisheries

However, a sustainable seaweed development project has still not been as thoroughly developed as other types of fishery. The Marine Steward Council (MSC) recognized its sustainability standard for seaweed separately from those of wild-capture fish and invertebrate fisheries at the MSC’s Technical Advisory Board (TAB) meeting in December 2013. The MSC is currently in the process of developing the standard for achieving sustainable seaweed harvests for both stock status and ecosystem impact (Marine Stewardship Council, 2014).

5.3 Multi-Criteria Decision Analysis

Sustainability and risk aspects should be taken into consideration for risk mitigating strategies for the seaweed supply chain. In that context, decision making can be complex due to trade-offs between sustainability and other factors of risk criteria. Some criteria have quantitative values, while others are qualitative and cannot easily be converted into quantitative data. It also needs to be kept in mind that there is more than one alternative for mitigating a seaweed supply chain’s risk. Solutions are either to design the best alternative or to select the one that best fits the needs of the supply chain. Assessment of risk mitigation strategies is multi-criteria in nature. Therefore, Multi-Criteria Decision

Analysis (MCDA) is strongly preferred for the decision making process of the risk mitigation strategies.

MCDA methods attempt to integrate explicit aspects of multiple criteria, primarily through either monetary or non-monetary factors, in aiding the decision making process. MCDA has the potential to solve problems in attempting to meet definite objectives with conflicting criteria (Belton & Stewart, 2002; Hwang & Yoon, 1981; Stewart, 1992). Conflicting criteria often require that one factor be determined in accordance with the priorities. While the perspectives of decision makers vary with respect to utilizing either qualitative or quantitative information to achieve a consensus of what best fits the priorities. MCDA can guide and support the decision making process through the use of a transparent and traceable analysis. MCDA also provides valuable support in reaching a general consensus among decision makers through the inclusion of a sensitivity analysis (Belton & Stewart, 2002; Bertsch, 2008; French et al, 2005; Geldermann et al., 2009). In general, the goal of the multi-criteria approach is to assist decision makers in making better decisions (Roy, 1990).

5.3.1 General Overview of MCDA

MCDA supports decision makers in integrating objective measurements with a value judgment in order to make a more explicit decision and to manage subjectivity. Subjectivity often occurs in the decision making process, especially when choosing the right criteria. Thus, expert skills are necessary for making effective decisions. MCDA is not applied in an effort to determine one optimal solution, but rather to develop multiple effective solutions (Belton & Stewart, 2002).

MCDA has become popular in many fields since Charnes and Cooper (1957) proposed goal programming and Keeney and Raiffa (1976) introduced the theory and methods for multi-attribute utility assessment. In the 1970s, MCDA was applied in multiple objective mathematical programming, specifically in multiple objective linear programming and discrete problems. In the 1980s, it became useful multi criteria decision support (Korhonen et al, 1992).

MCDA approaches can generally be categorized into two methods: Multi-Attribute Decision Making (MADM) and Multi-Objective Decision Making (MODM). MADM focuses on the assessment of a finite set of alternatives which have a separate solution space. MODM, on the other hand, emphasizes alternatives which are restricted by constraints and have continuous solution space (Hwang & Yoon, 1981). Similarly, Korhonen et al. 1992 classified MCDA problems into discrete explicitly defined alternatives and continuous implicitly defined alternatives.

Schools of thought of MADM can be categorized into either the American or the French, also termed European, schools of thought. The American school assumes that Decision makers are familiar with the utility criteria and express the relative importance for each criterion clearly in order to transparently reveal and explain the preferences of Decision makers. The American school covers Multi-Attribute Utility Theory (MAUT) or Multi-Attribute Value Theory (MAVT) (Dyer, 2005; Siskos et al., 2005), analytic hierarchy process (AHP) (Saaty, 1980), and analytic network process (ANP) (Saaty & Vargas, 2006). One of the shortcomings of the American approach is loss of information due to a higher aggregation of criteria results. In fact, good and poor criteria values can compensate each other.

Approaches of the European school are not fully compensatory and require less information from decision makers. The approach allows for allocating qualitative and quantitative data on an open scale and incorporate uncertain information through probability distribution, fuzzy sets, and threshold values. Preference, indifference, and incomparabilities can be analyzed if there is not enough available information. Decision makers are usually not fully aware of their preferences in a real situation, or they cannot clearly demonstrate their preference (Oberschmidt et al., 2010).

Additionally, Belton and Stewart (2002) classified the schools of thought surrounding the MCDA approach into three main approaches: value function based methods, satisfying and aspiration-based methods, and outranking methods. The value measurement theory constructs a means of associating a real value for each alternative to produce a preference order of the alternatives that is consistent with decision makers' value judgments. The satisfying and aspiration based method directly applies the partial preference functions without further transformation, with the preference function values having cardinal measurements. The preference functions of outranking models are applied directly to partial preference functions, which are assumed to have been defined for each criterion, with no underlying aggregative value function. The outranking methods focus on pairwise comparison of alternatives, identifying vetoes and incomparabilities, as well as assessing preferences and indifferences. The output of outranking methods is not a value for every alternative, but rather an outranking relation of the set of alternatives. The two most leading outranking methods are the Elimination and Choice Expressing Reality (ELECTRE) methods (Roy, 1973) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (Brans & Mareschal, 1982). Roy and his colleagues developed ELECTRE at the University of Paris Dauphine, while PROMETHEE was proposed by Brans and associates from the Free University of Brussels (Belton & Stewart, 2002; Figueira et al., 2005).

MCDA is becoming a more widely used tool in international forums and for multi-disciplinary problems (Geldermann & Schöbel, 2011; Korhonen et al., 1992), with its methods being implemented in many areas. For example, the MCDA is applied in technique assessment, energy selection, designing public policy of energy and environment, and energy planning (Diakoulaki & Karangelis, 2007; Geldermann & Rentz, 2005; Greening & Bernow, 2004; Løken, 2007; Oberschmidt et al., 2010). MCDA has also been widely applied in the agricultural and fisheries fields (Sethi et al., 2005). Wang et al. (2009) reviewed sustainable energy decision making, and Zhou et al. (2006) also reviewed energy and environmental modeling in accordance with MCDA methods.

5.3.2 Decision Process of MCDA

The three main stages of MCDA consist of problem identification and structuring, model building and application of the model to inform and challenge thinking, and determination of a plan of action (Belton & Stewart, 2002). Further, the MCDA process can be divided into nine steps, which is potentially somewhat repetitive and interdependent due to the growing insight into the underlying decision problem (Eigner-Thiel et al., 2013; French & Geldermann, 2005). The steps of the process are as follows:

1. Define the strategic objective
   The first step is needed to define and specify the strategic objective in order to develop a common understanding of the problem. In this step, we structure the problem, which refers to 'the process of making sense of an issue, identifying key concerns, goals, stakeholders, actions, uncertainties, and so on (Belton & Stewart, 2002). Identifying and structuring the objective provides more insight for better decisions (Keeney, 1992).

2. Compile alternatives
   Identification of alternatives is derived from the strategic objective. Thus, alternatives which can potentially meet these objectives need to be identified. Alternatives should be comparable to one another, meaning that they address the same system borders and correspond with the same parameters. Moreover, they must be exclusive, which means that the decision makers can choose only one of the alternatives (Belton & Stewart, 2002).

3. Define the criteria hierarchy
   A criterion is ' a particular perspective according to which decision alternatives may be compared, usually representing a particular interest, concern or point of view' (Belton & Stewart, 2002). Other scholars use terms of criteria as a measure of effectiveness, performance or quality (Keeney, 1992). According to Stewart (1992), criteria are commonly developed in a hierarchical structure, starting from something general and leading to more specific criteria. The purpose of structuring hierarchical criteria is to breakdown the strategic objectives into measurable units (Bertsch, 2008) .

4. Determination of criteria values
   After structuring a problem into a criteria hierarchy, it is necessary to investigate and calculate the values of the criteria for each alternative. Defining the value for each criterion is important for measuring the degree to which the overall objectives are met by these criteria (Keeney, 1992).

5. Assign a weight to each criterion
   There are a variety of structured methods for determining weights which adequately express the level of importance of a criterion with respect to the overall decision. Weighting methods, for example, are the swing technique (Winterfeldt & Edwards, 1986), the ratio method or Simple Multi-Attribute Rating Technique (SMART), SMART using Swings (SMARTS), SMART Exploiting Ranks (SMARTER) (Edwards, 1977; Edwards & Barron, 1994). The SMART and swing method are simple multi-attribute weighting methods based on ratio estimation (Mustajoki, Hamalainen, & Salo, 2005), trade-off method (Keeney & Raiffa, 1976), eigen vector (Saaty, 1980), and unit weighing, i.e., equal weighing after standardizing the attributes (Schoemaker & Waid, 1982).The most commonly used weighing methods of multi-attribute utility

measurement are the ratio method, the swing weighing method, the trade-off method and the pricing-out method (Borcherding et al., 1991; Weber & Borcherding, 1993).
The overall values of the alternatives are comprised of the values of the alternatives with respect to each criterion and of the weight of the attributes. The sum of the weights is normalized to one. S everal studies showed that different weighting methods may give diverging results (Borcherding et al., 1991; Weber & Borcherding, 1993).

6. Define method-specific information as utility or preference functions, with corresponding thresholds
   The type of preference function depends on the method. For example, within the application of MAUT/ MAVT, utility/value functions are applied, while the PROMETHEE procedure make use of preference functions (Belton & Stewart, 2002).

7. Calculate the results with the chosen MCDA method and make the results visible with graphs and charts to assess the alternatives
   Various methods of MADM provide the software to help decision makers calculate the data from the decision table, utilizing criteria, values, and weights. Some methods require specific information, established parameters for the preference functions. It is important to present and communicate the calculated result in an understandable way so that people from various disciplines can fully understand the information. A visual display of data is commonly used in a user-friendly manner, typically with bar charts, pie charts or trend lines (Eigner-Thiel et al., 2013).

8. Conduct a sensitivity analysis
   To analyze the stability of the result or important parameters, it is essential to conduct a sensitivity analysis. The impact of changes in the weight values assigned to criteria, for example, can be analyzed with such an analysis (Belton & Stewart, 2002).

9. Chose an alternative
   Based on the information obtained from the result and the sensitivity analysis, the DM should be able to make an insightful decision.

In this research, the MCDA approach is used to focus on various grouped criteria. Furthermore, the rank of alternative risk mitigation strategies is analyzed by PROMETHEE. As an MCDA method, PROMETHEE is selected to assess the mitigation strategies because it seems to be an appropriate method for assessing the mitigation strategies. The next section reviews MCDA and the PROMETHEE approach as a decision support tool to mitigate risks in a seaweed supply chain.

5.3.3 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)

PROMETHEE represents one of the best known and most widely used MADM methods. A comprehensive overview of the applications of PROMETHEE is given by Behzadian et al. (2010). According to Oberschmidt et al. (2010), PROMETHEE offers a simple design, easy calculation and application, stable results, is more transparent, easy to understand even for decision makers who are not familiar with MADM, and is easy for group decision making. Additionally, the preference functions allows for hesitations in decision makers' preferences, as well as uncertainties in criteria. The threshold values are defined for applying generalized preference functions. Sensitivity analyses enables the investigation of the influence of different preference functions and criteria weights, as well as weight stability intervals (Al-Shemmeri et al., Løken, 2007; Wang et al., 2009).

PROMETHEE was initially developed by Brans (1982) as an outranking approach for explicitly defined alternatives. Afterwards, the method was improved by Brans and his colleagues (Brans & Vincke, 1985; Brans et al., 1986). PROMETHEE is based on pairwise comparisons between alternatives and can be used for quantitative and qualitative criteria (Brans & Mareschal, 2005; Brans & Vincke, 1985; Brans et al., 1986; Roy, 1990).

The development of PROMETHEE includes a Geometrical Analysis for Interactive Aid (GAIA). The GAIA helps to visualize the main features of a decision problem in order to easily identify conflicts or synergies between criteria, to identify clusters of actions and to highlight remarkable performances.

Over the years, several extensions of PROMETHEE have been developed, e.g., the development of the GAIA-plane for a better visualization of the results and interdependences between criteria, alternatives and weights (Brans & Mareschal, 1994). Thus, the different versions of PROMETHEE are identified from I to VI. Oher enhancements have also been developed to further adapt the approach to meet decision makers needs, e.g., Fuzzy PROMETHEE (Geldermann & Rentz, 2001; Geldermann et al., 2000). The most applied version of PROMETHEE are PROMETHEE I and II.

PROMETHEE I is a partial outranking, which includes preferences, indifferences and incomparabilities between alternatives. PROMETHEE I is based on positive and negative flows. The objective of PROMETHEE I is to find a partial ranking that can be transformed into PROMETHEE II through complete ranking. PROMETHEE II is a complete ranking of the alternatives which are based on the net flow . It covers preferences and indifferences or preorder. A complete preorder can be obtained by collecting aggregate information within the net outranking flows (Brans & Mareschal, 2005).

Brans and Mareschal (2005) point out that the calculation of the net outranking flow in PROMETHEE II goes along with a loss of information, as compared to PROMETHEE I, because positive and negative criteria values can compensate each other, similar to utility functions in MAUT (Belton & Stewart, 2002). Thus, it is recommended to always use both options, because the complete ranking based on PROMETHEE II can only be fully understood if the partial ranking based on PROMETHEE I are also known.

PROMETHEE has two stages: 1) the construction of an outranking connection on a finite set of actions and 2) the exploitation of this relation to reach maximum criteria for each alternative (Brans et al., 1986). One specific characteristic of PROMETHEE is the definition of an individual preference function which is necessary for each criterion. For such preference functions, a set of six generalized criteria has been developed (Brans & Mareschal, 2005).

The following paragraphs contain descriptions of PROMETHEE and its procedure, according to Oberschmidt et al., (2010.

Let A = {a_1,…;a_i… ; a_m} represent a finite set of alternatives and C = {c_1;… ; c_j;…;c_n} define the set of relevant criteria. There is no objection to consider some criteria to be maximized and others to be minimized. The goal for decision makers is to identify an alternative which optimizes all of the criteria.

After determining the criteria values $f_j(a_i)$ for each alternative a_i and each criterion c_j, the procedure for preference elicitation using the proposed modified approach based on the original PROMETHEE I and II (Brans et al., 1986; Brans & Mareschal 2005) includes the following steps which are performed for all of the alternatives under consideration:

1. The solution of a multi-criteria problem depends not only on the basic data included in the evaluation table, but also on the decision makers themselves. All individuals have some preferences, thus, there is no absolute best solution. The best compromise solution also depends on the individual preferences of each decision maker. Therefore, additional information representing these preferences is needed.

   For each criterion c_j, one preference function p_j is determined; p_j reflects the degree of preference of alternative ai* over alternative a_i regarding the respective criterion depending on the difference in criteria values:
$$\boldsymbol{p_j}(\boldsymbol{d_j}(\boldsymbol{a_{i*}}, \boldsymbol{a_i})) = \boldsymbol{p_j}(\boldsymbol{f_j}(\boldsymbol{a_{i*}}) - \boldsymbol{f_j}(\boldsymbol{a_i})) \quad where \quad p_j \in [0,1] \tag{2}$$

   For a usual criterion, the two alternatives are considered to be indifferent if p_j = 0. Alternative a_{i*} is strictly preferred over a_i regarding criterion c_j, if p_j = 1. Other types of preference functions allow for an indifference threshold *q* (alternatives a_{i*} and a_i are indifferent if $p_j \leq q$), as well as a threshold for strict preference *p* (alternative a_{i*} is strictly preferred over a_i if $p_j \geq p$), with (gradually increasing) weak preference between the two threshold values. Six generalized preference functions are shown in Figure 5-1. Further details on preference functions can be found in Brans et al. (1986), and Anand and Kodali (2008).

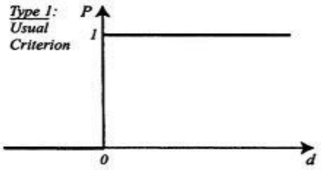
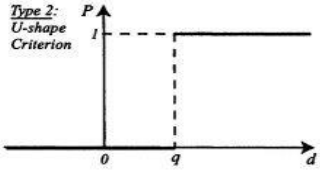
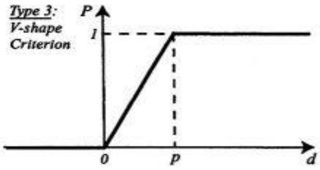
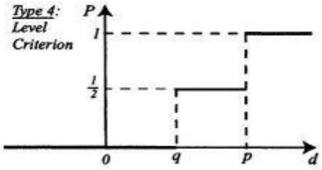
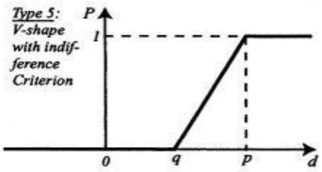
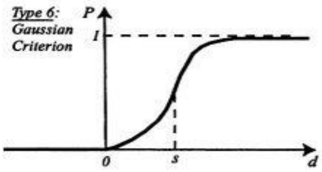
Generalised criterion	Definition	Parameters to fix
Type 1: Usual Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$	–
Type 2: U-shape Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$	q
Type 3: V-shape Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$	p
Type 4: Level Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
Type 5: V-shape with indifference Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{p-q} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
Type 6: Gaussian Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

Figure 5- 1: Six generalized preference functions (Brans & Mareschal, 2005)

2. One weighing vector $w^T = [w_1; \ldots; w_j; \ldots; w_n]$ will be applied for all alternatives and is defined to reflect the (subjective) relative importance of the criteria, where the sum of all weights equals a value of one.
3. To determine the degree of dominance of alternative a_{i*} over a_i with regard to all criteria, the outranking relation π is calculated by taking all weightings into consideration:

$$\pi(a_{i*}a_i) = \sum_{j=1}^{n} w_j \cdot p_j\big(d_j(a_j, a_{j'})\big) \quad where\ \pi(a_{i*}a_i) \in [0,1] \tag{3}$$

   This measure allows for the comparison of two alternatives with regard to all criteria.

4. To compare one alternative with all of the other available alternatives based on all criteria, the outranking flows Φ are calculated. The positive or leaving outranking flow Φ^+ is a measure of the outranking character of alternative a_{i*}:

$$\Phi^+(a_{i*}) = \frac{1}{m-1} \sum_{i=1}^{m} \pi(a_{i*}, a_i) \tag{4}$$

Based on the positive outranking flows, the following preorders are induced:

– $a_{i*}P^{+}a_i$, i.e. a_{i*} is preferred to a_i if $\Phi^+(a_{i*}) > \Phi^+(a_i)$

– $a_{i*}I^{+}a_i$, i.e., a_{i*} and a_i are indifferent if $\Phi^+(a_{i*}) = \Phi^+(a_i)$.

- The negative or leaving outranking flow Φ^- is a measure of the outranked character of alternative a_{i*}:

$$\Phi^-(a_{i*}) = \frac{1}{m-1}\sum_{i=1}^{m}\pi(a_i, a_{i*}) \tag{5}$$

Based on the positive outranking flows, the following preorders are induced:

– $a_{i*}P^{-}a_i$, i.e. a_{i*} is preferred to a_i if $\Phi^-(a_{i*}) < \Phi^-(a_i)$

– $a_{i*}I^{-}a_i$, i.e,. a_{i*} and a_i are indifferent if $\Phi^-(a_{i*}) = \Phi^-(a_i)$.

5. The partial preorder according to PROMETHEE I can be defined based on the intersection of the two preorders from the positive and the negative outranking flows:
   - a_{i*} is preferred to a_i if:

     – $a_{i*}P^{+}a_i$ and $a_{i*}P^{-}a_i$, or

     – $a_{i*}P^{+}a_i$ and $a_{i*}I^{-}a_i$, or

     – $a_{i*}P^{-}a_i$ and $a_{i*}I^{+}a_i$

   - a_{i*} and a_i are indifferent if $a_{i*}I^{+}a_i$ and $a_{i*}I^{-}a_i$.
   - Otherwise, a_{i*} and a_i are incomparable (a_{i*} R a_i)
6. A complete preorder avoiding incomparability can be defined according to PROMETHEE II based on the net flow $\Phi^{net}(a_{i*}) = \Phi^+(a_{i*}) - \Phi^-(a_{i*})$:
   - a_{i*} is preferred to a_i if $\Phi^{net}(a_{i*}) > \Phi^{net}(a_i)$.
   - a_{i*} and a_i are indifferent if $\Phi^{net}(a_{i*}) = \Phi^{net}(a_i)$.

5.4 Application of the PROMETHEE to Assess Risk Mitigation Strategies for Seaweed Supply Chains

This section describes the implementation of PROMETHEE to support the decision making process for assessing risk mitigation strategies in a seaweed supply chain in Indonesia. The production of semi-refined carrageenan in Takalar sub-province, South Sulawesi is chosen for our illustrative case study. The region is one highest ranking seaweed cultivation regions, for both *Eucheuma* and *Gracilaria* seaweed types, making it a strategic location for a case study. The region is also geographically close to the Makassar shipping harbor in the eastern part of Indonesia. The implementation of the decision support tool helps the Decision makers, especially carrageenan and agar companies, but also government in Indonesia, who have to choose the most sustainable mitigation strategies for a specific area.

5.4.1 Definition of the Objective

The first step to mitigate risks in a seaweed supply chain is defining the objective. An objective can be defined as ‘a statement of something that one desires to achieve’, and has three characteristics: a decision context, an object and a direction of preference (Keeney, 1992). Based on the research question, the strategic objective for the present research is the identification of a reliable model for mitigating seaweed supply chain risks in Indonesia to achieve sustainability within the sector.

5.4.2 Alternative Strategies to Mitigate Seaweed Supply Chain Risks

According to Stecke and Kumar (2009), outsourcing, globalization and decentralization are the main factors that result in supply chain risks. As the distance and time required for distributing materials between supply chain tiers increases, it becomes more difficult for supply chain members to control and coordinate between themselves. Most seaweed processing companies in Indonesia are spread out across the western part of Indonesia, while most seaweed cultivation areas are located in the eastern part. Logistic networks that connect farmers to seaweed manufacturing companies are mainly through sea-based transportation. Thus, it is not easy to successfully integrate and manage all related works in a seaweed supply chain, particularly in terms of supply.

Therefore, these conditions can lead to an adverse event in a supply chain. High risks of the seaweed supply chain are mostly caused by supply risks, such as low quality of raw dried seaweed (RDS), scarcity of RDS and price fluctuation of RDS as has been described in Chapter 4. Mitigating the risks within a seaweed supply chain can be achieved if effective processing and quality controls, particularly in RDS, is in place near a seaweed farming region.

The risks in a seaweed supply chain might be minimized by setting up a production plant close to cultivation areas in order to improve quality control of RDS and increase information access among the seaweed supply chain members. The proposed alternatives for mitigating seaweed supply chain risks in Indonesia are as follows: building a small scale seaweed processing facility owned by a group of farmers or a cooperative, building a large seaweed plant owned by a private company, and building a seaweed industrial cluster.

The first alternative is characterized by building a small scale seaweed processing facility owned by a group of farmers or a cooperative within the context of village norms and their cultures. Seaweed farmers, however, are categorized as small-scale enterprises which do not have much working capital for setting up a seaweed processing plant. Therefore, they have to build a group or a cooperative to effectively handle manage financial concerns and other problems. A strong farmer’s institution is a common need among farmers in order to improve their bargaining position in their industry (Baga, 2013). For example, in a larger group it is more likely that they can borrow financial capital from formal financial institutions.

The second alternative is building a large scale seaweed plant. The owner of a large company can be investors both from Indonesia and abroad. A seaweed industrial cluster is proposed as the third alternative. A cluster is ‘a geographic concentration of a specific industry, together with its supporting and related industries and service providers, including government and other institutions such as universities and trade associations’ (Porter, 1998). Cluster organizations are commonly a partnership between public and private institutions.

It will now be investigated whether these alternatives can improve resilience in the face of supply chain disturbances such as quality issues and unstable prices in a comprehensive way. The advantages of building a company near seaweed sources are a shortened supply path, reduced trading games, increased value added particularly for seaweed farmers, minimized handling and processing steps (Neish, 2013).

The proposed alternatives also support the idea of decentralization in Indonesia to different extents, primarily with respect to the way in which a local government regulates and manages their region. Decentralization policies have enabled seaweed farmers to interact more closely with government units. In the long run, the three alternative strategies could create job opportunities and alleviate poverty within Indonesia, especially in rural coastal areas. The differences for each alternative are described in Table 5-1

Table 5- 1: Alternative of risk mitigation strategies in a seaweed supply chain

Concept	**Alternative of mitigation strategies**		
	A small seaweed manufacturing	**A large seaweed manufacturing**	**A seaweed industrial cluster**
Ownership	Seaweed farmers in collaboration with local or large traders	Outside investor	Outside investor or group of local people
Format of company	Cooperative	Private company	Private-public company or public company
Production method	Gel press method	Gel press method or alcohol precipitation	Gel press method or alcohol precipitation
Products	ATC, SRC and agar strips	ATC, SRC, RC, and agar	ATC, SRC, RC, and agar
Land area (m^2)	1,750	10,000	17,500

5.4.3 Criteria of Risk Mitigations: Sustainability and Risk Criteria

The overall objective of this research needs to be broken down into operational criteria. Criteria are important factors in MCDA as a basis for assessing alternatives. A criteria hierarchy displays the top-down approach of starting with the overall objective and expanding it into smaller, more detailed targets, which should adequately cover all environmental, economic, social and risk aspects, but not create redundancy.

A sustainable seaweed supply chain should incorporate the three principles of sustainable development: economic growth, environmental conservation and social equality (the United Nations Conference on Environment and Development, 1993). The term of sustainability should be down into criteria that can be broken measured.

Environmental data are required to assess the impacts of seaweed manufacturing; economic data are needed to calculate the investment or duration of supply contracts and social criteria are essential for determining how local people are engaged in terms of existence of the seaweed industry. Risk factors are also required to assess the possibility of an adverse event in a seaweed supply chain. In this study, most of the sustainability targets and attributes refer to Eigner-Thiel et al. (2013).

The measurement scale for every criterion should be clearly determined, both in terms of a quantitative and a qualitative value (Georgopoulou et al., 1998). The unit of measurement for criteria aspects consists of nominal, ordinal, interval, and ratio scales. Nominal scales include separating and classifying the objects to be measured into distinct categories and then calculating the value, while ordinal scales assign objects into classes, with the classes then being ranked with respect to one another; alternatively, the objects themselves can be ranked directly. Value or consequence of selected criteria can affect the selection of the alternative (Belton & Stewart, 2002).

1. Environmental criteria

1.1 Waste water

The criterion refers to the waste water from a seaweed industry. Seaweed production needs a large amount of water for every step of the process. The criterion should be taken into consideration in terms of freshwater quantity (m^3) annually. The less the value for waste water is, the better the assessment result.

1.2 Solid waste

Solid waste means any waste from seaweed production and its cultivation (metric tons) per year. A smaller quantity of smaller waste indicates less consequence to the environment.

1.3 Electric energy consumption

The seaweed industry depends on electric power for transforming raw dried seaweed into a product. The criterion is the form of energy consumption which uses electric energy (MJ) per year. The more electricity is consumed, the worse the impact to the environment.

1.4 Industrial area

An industrial area is an area for building a seaweed manufacturing in square meters (m^2). The industrial area should consider space for drying, processing, water availability, access to supply, and minimizing conflicts between food productions and nature conservation. The more land area is needed, the worse impact to the environment.

2. Economic criteria

2.1 Net present value (NPV)

Net Present Value (NPV) is a financial indicator used to analyze the profitability of an investment for long-term assets. The NPV describes the net present value of all expected cash flows both positive and negative value. The formula for NPV is as follows:

$$NPV = \sum_{t=0}^{N} \frac{CF_t}{(1+i)^t} \quad (5)$$

t= 0, …, n

where t represents any specific period, CF_t indicates the cash flow at the end of the period, i represents the cost of capital, and N is the number of periods comprising the economic life of the investment. Cash inflows are positive values of CF_t and cash outflows are negative values of CF_t. A positive NPV means that the investment is profitable, while a negative value indicates that the return is less than the cost of capital, so that the project should be rejected. If NPV equals zero, accepting or rejecting the project is an indifferent investment (Peterson Drake & Fabozzi, 2010).

In this study, the economic life of the project is 10 years, while the interest rate is calculated at 11% in accordance with the Bank of Indonesia (2014). The monetary value is initially considered in Indonesian Rupiah (IDR) and is then converted to Euro according to the official conversion rates of November 2014. The higher of NPV, the better the result.

2.2 Length of supply contract

A supply contract is an agreement about the terms of the working relationship for the supply of raw materials between a seaweed supplier and a seaweed processor in a specific period of time. The contract includes contractual terms and conditions, terms of payment, and any other aspect of the relationship that the two parties have determined to be necessary, such as responsibilities of parties, performance criteria and review processes, as well as pricing and invoicing processes. The relationship between the farmers and the manufacturers is mutualism. Farmers provide a specified quantity that meets a predetermined quality standard, which is then sold exclusively to the producers at a predetermined price. Thus, seaweed farmers ensure the availability of raw materials and commit to provide a specific material, as determined by processors.

The contract’s value is determined based on the running time of supply contracts. According to interviews with large traders, the maximum duration for a supply contract is five years, due to the relatively short lifecycle of seaweed. The classification of a supply contract’s duration is categorized into five groups: 1 point = 0-1 year, 2 points = 1-2 years, 3 points = 2-3 years, 4 points = 3-4 years, and 5 points = 4-5 years. The longer the contract between the suppliers and the operating company, the higher the operating company’s planning safety (Eigner-Thiel et al., 2013).

2.3 Shared revenue

Profit sharing can be a powerful means for sustainability in a seaweed supply chains. If the suppliers (farmers) participate in profit realization, the criterion is assessed positively (1). Otherwise, if there is no possibility to join in profit sharing, it is assessed negatively (0 points). Shared revenue is primarily created between the seaweed farmers and seaweed manufacturers.

2.4 Risk sharing

A relevant philosophy of supply chain risk, as identified by Jüttner (2005), is the willingness to accept joint risks. It is important to find out which risks are accepted as joint risks and which risks are only considered for a specific supply chain member. This idea is also supported by Sodhi and Tang (2012), decision makers should build a share of the risks within members of a supply chain.

Risk sharing or risk distribution is a method of risk management in which the consequences of risk are distributed among members of a seaweed supply chain, depending on a predetermined agreement. The criterion is assessed positively (1) if risk sharing is an option for supply chain members. Otherwise, if there is no possibility to join in risk sharing, it is assessed negatively (0 points).

3 <u>Social criteria</u>

3.1 Collaborative decision making

This criterion concerns the communities' participation as a horizontal collaboration in the seaweed industry's development. A close and cooperative relationship is necessary between supply chain members and the local people or stakeholders. Collaborative decision making can be conducted through holding discussions or shared responsibility for building consensus among stakeholders. The main aspect is a collaborative culture which consists of trust, mutual understanding, information exchange, and openness and communication. Collaboration is not always easy to implement, because supply chain members often lack an understanding of what collaboration really implies to a supply chain's performance (Barratt, 2004). Stakeholders of the seaweed industry should be involved in the decision making process which includes planning, implementing, monitoring, and evaluating supply chain activities.

Frey (2006) suggested five levels of community linkage: networking, cooperation or alliance, coordination or partnership, coalition, and collaboration. The levels differ by purpose, the structure of decision making and the nature of leadership. The five levels of collaboration and their characteristics are described in Table 5-2. The stronger the collaboration, the better the overall planning process will be.

Table 5-2: Five level of collaborations and their characteristics

Level of collaboration	Networking (1)	Cooperation (2)	Coordination (3)	Coalition (4)	Collaboration (5)
Relationship Characteristics	Aware of organization, loosely defined roles, little communication, and all decisions are made independently	Provide information to each other, somewhat defined roles, formal communication, and all decisions are made independently	Share information and resources, defined roles, frequent communication, and some shared decision making	Share ideas, share resources, frequent and prioritized communication, and all members have a vote in decision making	Members belong to one system, frequent communication is characterized by mutual trust, and consensus is reached on all decisions

Source: Adapted from Frey (2006)

3.2 Creating job opportunities

Promoting job growth is a central challenge in developing countries to support poverty alleviation in the long run. The seaweed industry creates a lot of job opportunities, especially for providing a livelihood in coastal communities. Full-time or part-time working opportunities are available in the seaweed industry. Absorption of labor work includes the labors in seaweed farming, such as working in maintenance, harvesting, and drying seaweed. Labor is qualitatively measured and further categorized into five categories: 1= Very low level of work opportunities, 2= Low level of work opportunities, 3= Moderate level of work opportunities, 4= High level of work opportunities, and 5= Very high level of work opportunities. The greater the number of workers within the seaweed industry, the lower the unemployment rate will be.

3.3 Shared-information

Providing information for the local population is the minimal engagement of obtaining participation. Locals should be informed about the workings of the seaweed industry, for example, what is being planned and what is expected to happen. It is essential to inform local people about the activities of a seaweed industry regularly through informational events or meetings. In consideration of our assessment, one point is assigned for each participating group and zero if no outsiders are allowed to participate. The more stakeholders are informed, the better (Eigner-Thiel et al., 2013; Peter et al.,2008).

4. Risk criteria

Risk criteria are not included in the triple bottom line of sustainability. Pfohl et al., (2010) found that companies within a supply chain should develop a common understanding of risks and agree on a risk evaluation standard. The risk criteria include process, control, supply, demand, exchange rate, regulatory and infrastructure risks. The criteria are all measured using qualitative values in accordance with a seven-point scale. The scale indicates the risk frequency of an adverse event, where 1 = never, 2 = rarely, the probability of an adverse event in about 10%, 3 = occasionally, in about 30%; 4 = Sometimes, in about 50%; 5 = Frequently, in about 70%; 6 = Usually, in about 90%, ;7 =

Every time (Sodhi & Tang, 2012). The higher the frequency of an event is, the higher the risk of the supply chain.

4.1 Process risk

Process risk refers to risks resulting from the production processes of carrageenan and agar. Process risks result from failure in chemical mixing, low quantity yields, machine breakdowns and low quality of products.

4.2 Control risk

Control risks are caused by inadequate safety stock, discrepancies in production scheduling and weaknesses of collaborative planning between focal companies and seaweed suppliers.

4.3 Supply risk

Supply risk refers to supplier activities or failures in inbound logistics. Sources of supply risk are fluctuation on RDS, scarcity of RDS, uncertain seaweed yields, low quality of RDS, delivery failure of RDS and long distance between seaweed farmers and focal companies

.

4.4 Demand risk

Demand risk is any risks that are connected to the outbound logistics flow or downstream supply chain actions. It can stem from uncertainty of customer demands, price fluctuations, and a mismatch of demand forecasting and switching consumers.

4.5 Exchange rate risk

Exchange rate risk refers to financial disturbances as a result of monetary policies, interest rate and political stability.

4.6 Regulatory risk

Regulatory risk is associated with variability of regulations in terms of frequency of changes in the laws and policies for the seaweed industry.

4.7 Infrastructure risk

Infrastructure risk refers to disturbances of water and electricity supplies that are necessary to support the seaweed industry.

Risk mitigation strategies and their criteria are shown in Figure 5-3. Table 5-3 shows the alternatives and attribute of risk mitigation strategies in a seaweed supply chain. Table 5-4 describes scale for criteria in a point scale is shown in

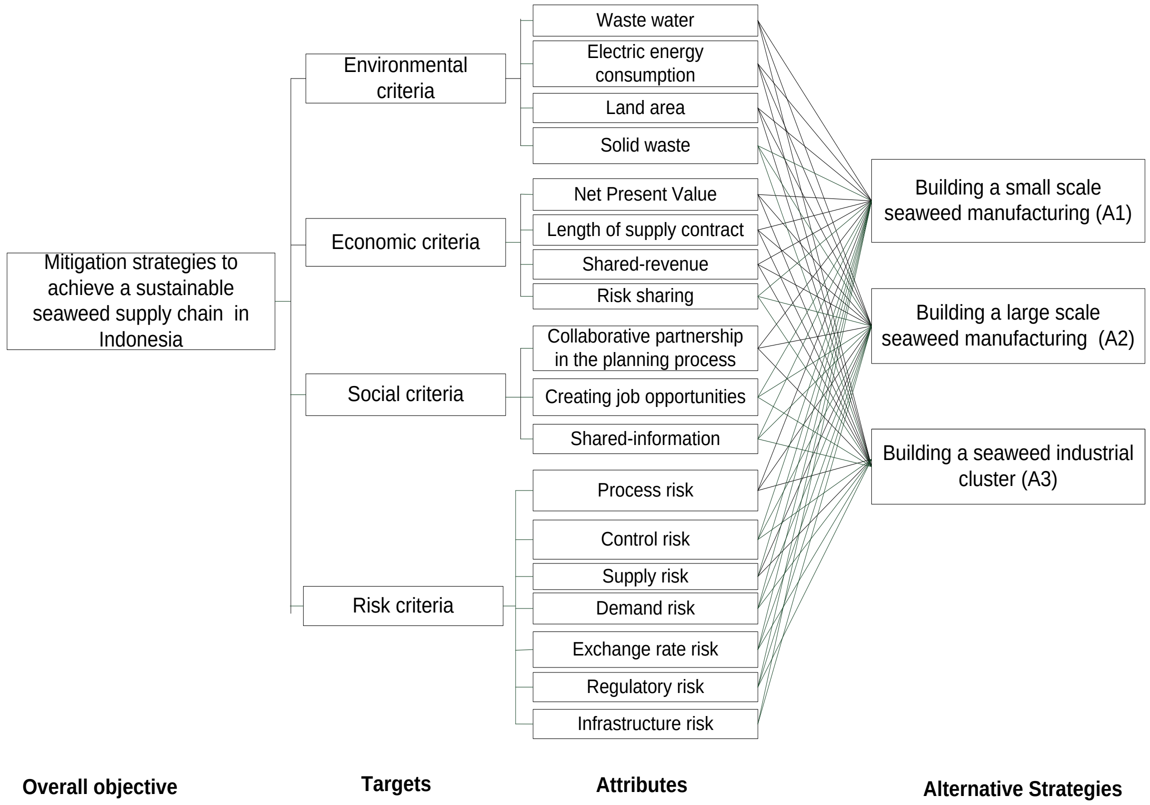


Figure 5- 2: Criteria hierarchy for risk mitigation strategies in a seaweed supply chain in Indonesia

Table 5-3: Alternatives and criteria of risk mitigation strategies in a seaweed supply chain

No	Attribute	Manifestation of the attribute for sustainability (Min/ Max)	Unit of measurement
1. Environmental targets			
1.1	Waste water	Min	m^3/year
1.2	Electric energy consumption	Min	MJ/year
1.3	Land area	Min	m^2
1.4	Solid waste	Min	ton/year
2. Economic targets			
2.1	Net present value	Max	Euro
2.2	Length of supply contract farming	Max	point
2.3	Shared-revenue	Max	Yes/no
2.4	Risk sharing	Min	Yes/no
3. Social targets			
3.1	Collaborative partnership	Max	point
3.2	Creating job opportunities	Max	point
3.3	Shared-information	Max	Yes/no
4. Risk targets			
4.1	Process risk	Min	point
4.2	Control risk	Min	point
4.3	Supply risk	Min	point
4.4	Demand risk	Min	point
4.5	Exchange rate risk	Min	point
4.6	Regulatory risk	Min	point
4.7	Infrastructure risk	Min	point

Table 5-4: Scale for the qualitative attributes

No	Criteria	Min/ Max	Scale 1-5: 1	2	3	4	5
1	Length of contract farming	Max	0 - 1 year	1- 2 years	2 – 3 years	3 – 4 years	4 - 5 years
2	Collaborative partnership	Max	Networking	Cooperation	Coordination	Coalition	Collaboration
3	Creating job opportunities	Max	Very low of work opportunities	low of work opportunities	moderately of work opportunities	High of work opportunities	Very high of work opportunities

No	Criteria	Min/ Max	Scale (1-7): 1	2	3	4	5	6	7
1	Process risks	Min	Never	Rarely, less than 10% of an adverse event	Occasionally, in about 30% of an adverse event	Sometimes, in about 50% of an adverse event	Frequently, in about 70% of an adverse event	Usually, in about 90% of an adverse event	Every time
2	Control risks								
3	Supply risk								
4	Demand risk								
5	Exchange rate risk								
6	Regulatory risk								
7	Infrastructure risk								

1.8.4. Determination of criteria values

The values for every environmental criterion include quantitative data calculated by the Umberto software, especially for the waste water, solid waste and electric energy consumption criteria. Waste water from SRC production comes from pre-treatment, alkali treatment and neutralization. The assumption is that the water added to the process will eventually become waste water. A small plant (125 ton annual capacity) produces 6,659.51 m^3 of waste water per year. In a large plant (500 ton annual capacity), 26,638.02 m^3 of waste water is accumulated per year. A seaweed industrial cluster accumulates waste water which comes from an SRC company and seaweed farmers. The seaweed is washed by water, where 0.0001 m^3 of water is needed for 1 kg of wet seaweed. Therefore, the total waste water for the industrial cluster is 28,294.65 m^3 (26,638.02 plus 1,656.62 m^3).

Solid waste is calculated by determining the losses of raw dried seaweed in the pre-treatment step; 13.43 tons on average for a small plant and 53.71 tons annually for a large company. In an industrial cluster, solid waste is not only accumulated from the production of semi-refined carrageenan, but also calculating the losses of wet seaweed during harvest. The total solid waste of a seaweed industrial cluster is 882.02 tons annually.

Electric energy consumption (MJ) is acquired from the calculation by Umberto with 2,024,908.16 MJ annually for a small plant, 8,099,632.65 MJ per year for a large plant and 8,117,632.65 MJ per year for an industrial cluster. With respect to an industrial cluster, the figure is calculated by considering the usage of a large plant plus the energy needed for packaging the seaweed, i.e., 0.001kWh (0.0036MJ) for packaging 1 kg of RDS. Thus, 500 tons of SRC needs 5,000 tons of RDS, so that the electricity consumed is 18,000 MJ annually. The required land area for building a small plant is 1,750m^2, while 10,000m^2 is necessary for a large plant, and 20,000 m^2 is utilized for building a seaweed industrial cluster. Economic targets are calculated through quantitative (i.e., NPV) and qualitative data. The calculation for each alternative is shown in Appendix

The evaluation of collaboration is difficult because the types of collaborations are difficult to convert into valid and reliable measurements (Frey, 2006). An industrial cluster demonstrates a strong collaboration between members in terms of economic and social aspects. With the cluster, there is regular communication, interaction and approaches that continuously support a common aim of cluster members (Morosini, 2004; Porter, 1998). Therefore, an industrial cluster has a higher level of collaboration than a small or large plant.

A seaweed industrial cluster encourages the absorption of the workforce, particularly with respect to cultivation labor of seaweed. The number of workers absorbed within the cluster is directly proportional to the production capacity specified in the cluster. The number of workers absorbed in the seaweed industrial cluster may account for up to 14.56% of the total labor force (Wibowo, 2011).

Risk data are taken from interviews with experts. The experts compare each risk criteria with each available alternative. The data is taken from questionnaires and interviews that were conducted by telephone.

All data should be comparable for every alternative and for each criterion. Thus, the units of measurement and the reference should be comparable. To compare all of the criteria for each alternative, it is important to determine the equivalence between the alternatives and the functional unit. In this case, a small plant has a capacity of 125 ton per year, compared with a large company and an industrial cluster which both have a 500 ton capacity per year. Therefore, the quantitative value of each criteria of a small plant multiplies four times, i.e. waste water, solid waste and electricity consumption, to accommodate the needs of large plants and industrial clusters.

5.4.4 Determination of Weights, Preference Functions, and Threshold Values

The weighting process is conducted after the criteria hierarchy has been presented and data for each alternative have been entered into the decision matrix. Weighting value indicates the relative importance of each criterion, a value which is a subjective element for decision makers (Eigner-Thiel et al., 2013). The preferential details of DMs for each alternative can be seen from the weighting factors (Belton & Stewart, 2002). In this case study, the weighting procedure used equal weighting for every attribute. The assumption is that sustainability and risk criteria have the same importance for mitigating seaweed supply chain risk.

The preference function for each criterion is determined based on the type of data. Quantitative data usually uses the preference function of type III (The V-shape) and type

V (linear). The choice of these types depends on whether an indifference threshold value is to be shown or not. Type I (usual type) and type IV (level) preference functions are more appropriate for qualitative criteria. The usual preference function is chosen in the case of a small number of levels on the criteria scale and when the different levels are considered to be quite different from one another, e.g., yes/no criteria. If the level value is differentiated in smaller deviations, the level preference function is more suitable. Type II (U-shape) and type VI (the Gaussian) functions are used less often. Type II is used for a special case of the type IV, and type VI is used less frequently because it is more difficult to correctly define the parameters (Anand & Kodali, 2008; Brans & Mareschal, 2005; Mareschal, 2012a).

The values of the *q* indifference threshold and of the *p* preference threshold indicate the preferences of a decision-maker. The indifference threshold (q) for a given criterion represents the largest deviation that is considered to be negligible in the comparison of two alternatives. A good rule of thumb is that the value of q is to start very small and to progressively increase until you feel that it is not negligible anymore. More precisely, the value for *q* is the standard deviation of the differences (Mareschal, 2011, 2012b).

The preference threshold (p) of a criterion is the smallest definition that can be considered as definitely important when comparing alternatives. The *p* value is usually determined by starting with a larger value and then progressively reducing the value until the DMs personal preference is not so well-established. A good way to determine the value of p, is that it should be smaller than the difference between the maximum and minimum values of the criterion. In this study, the value of p is the difference between the maximum and minimum value of each criterion, which is very close to the suggested value (Mareschal, 2011). Table 5-5 shows the values for each criteria of every alternative.

Table 5- 5: Values of criterion of each alternative for mitigating seaweed supply chain risk

Attribute	Type of preference function	Threshold value		Alternative		
		Indifference threshold (q)	Preference threshold (p)	A small seaweed plant (A_1)	A large seaweed manufacturing (A_2)	A seaweed industrial cluster (A_3)
1. Environment						
1.1 Waste water	V	500	1,500	26,638.02*	26,638.02	28,294.65
1.2 Solid waste	V	50	800	53.72*	53.72	882.02
1.3 Electric energy consumption	V	2,000	18,000	8,099,632.65*	8,099,632.65	8,117,632.65
1.4 Land area	V	2,000	13,000	7,000*	10,000	17,500
2. Economy						
2.1 Net present value	V	50,000	14,000	32,143.50	104,544	170,382.00
2.2 Length of supply contract	IV	1	4	2	1	5
2.3 Shared revenue	I	-	-	0	0	1
2.4 Risk sharing	I	-	-	0	0	1
3. Social						
3.1 Collaborative partnership	IV	1	4	3	1	5
3.2 Creating job opportunities	IV	1	3	4	3	5
3.3 Shared information	I	-	-	1	0	1
4. Risk	Risk					
4.1 Process risk	IV	2	3	4	3	2
4.2 Control risk	IV	2	3	5	3	2
4.3 Supply risk	IV	1	4	3	5	2
4.4 Demand risk	IV	1	2	5	4	3
4.5 Exchange rate risk	IV	1	2	5	4	4
4.6 Regulatory risk	IV	1	2	2	3	2
4.7 Infrastructure risk	IV	1	2	3	4	5

5.4.5 Results and Visualization

Results are calculated using the Visual Promethee software (Mareschal, 2010) and MCDA tools developed by Chair of Production and Logistics, University of Goettingen, Germany (2013). Table 5-6 shows the outranking flows of each alternative. The Φ+ (phi plus) measures the relative strength of the alternatives, with higher values being better. On the other hand, Φ^- (phi minus) indicates relative weaknesses with respect to alternative comparisons, i.e., the smaller the better. A seaweed industrial cluster shows the greatest strengths of a small plant and a large company. Therefore, building an industrial cluster has the highest outflow. However, a seaweed industrial cluster also has weaknesses with respect to the individual criterion. Building a seaweed industrial cluster can influence adverse impacts to the environment, such as the large amount of solid waste produced by industrial cluster in comparison to is the other alternatives

Table 5- 6: Outranking relations and flows

	A small plant	A large company	An industrial cluster	Φ+
A small plant	0.000	0.106	0.315	0.210
A large company	0.051	0.000	0.281	0.166
An industrial cluster	0.364	0.343	0.000	0.353
Φ⁻	0.208	0.224	0.298	

PROMETHEE I showed that an industrial cluster is incomparable to the other alternatives, a small plant and private company. Incomparability arises due to the vastly different profiles and one being apparently better on some criteria, while the other alternative is better with other criteria. An industrial cluster has quite different characteristics in comparison to a small plant and a large company; however, it does not mean that the alternatives cannot be compared. Generally, the determination of incomparability in the PROMETHEE I makes it easier for decision makers to recognize difficult choices (Figure 5-3).

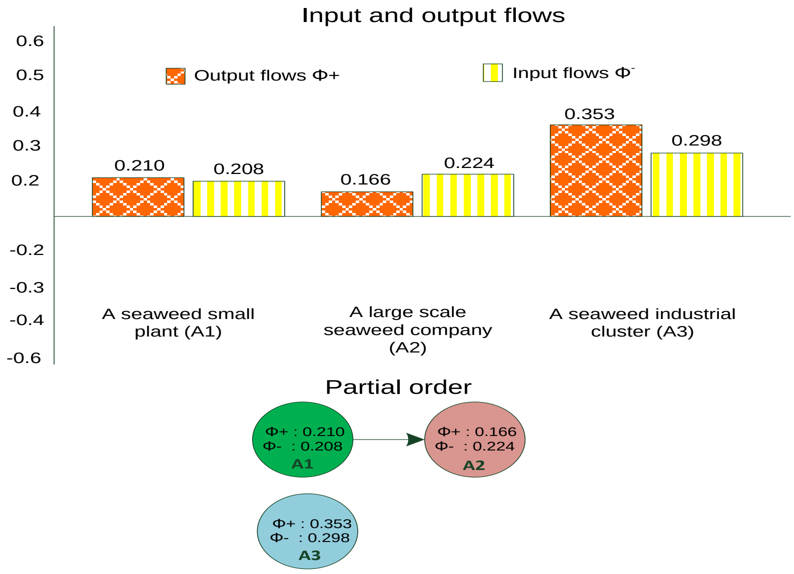


Figure 5-3: Result of PROMETHEE I

Risk mitigation strategies are ranked based on PROMETHEE II which shows the net flow. Due to the information gained with respect to net flows, the rank of the strategies can be designated as building an industrial cluster, a small plant, and a large company, respectively (Figure 5-4).

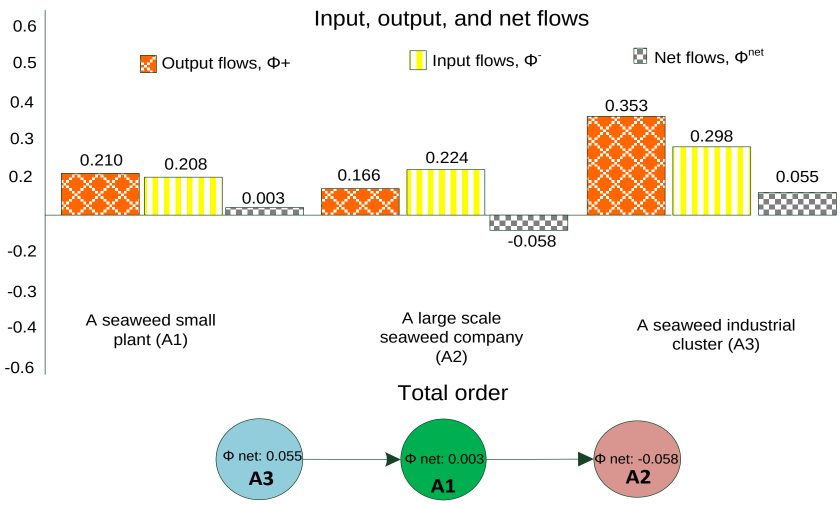
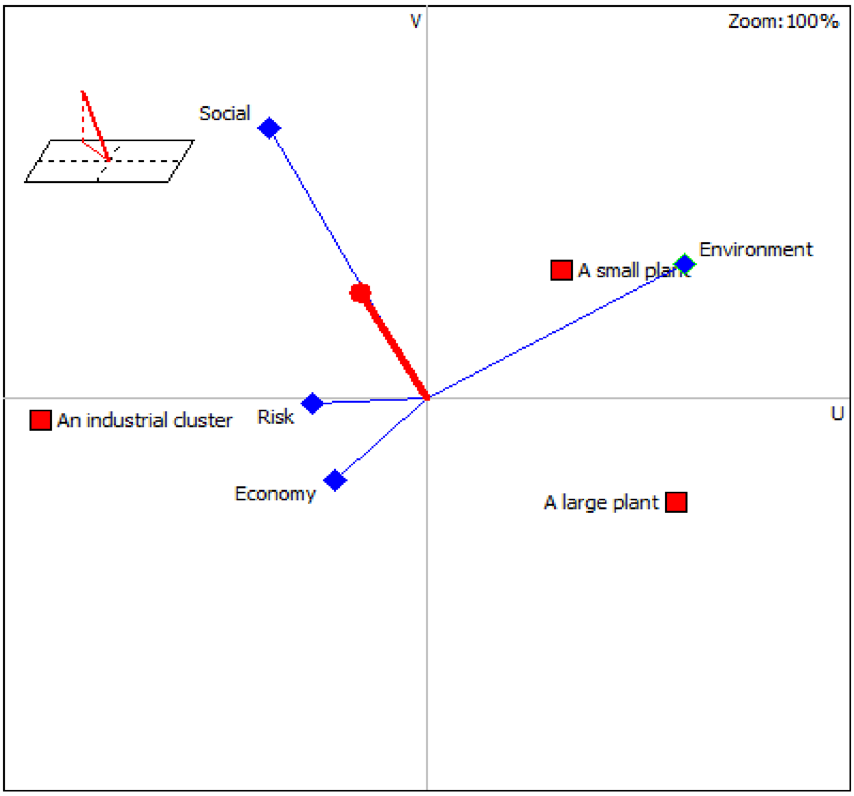


Figure 5- 4: Ranking of mitigation strategies to minimize supply chain risks

GAIA plane complements the information gained from the PROMETHEE ranking. In this case study, a GAIA plane is shown in Figure 5-5. A seaweed industrial cluster has more advantages with regards to social, risk, and economic criteria than the other alternatives. On the other hand, building of a small plant is the most advantageous in terms of environmental preservation.



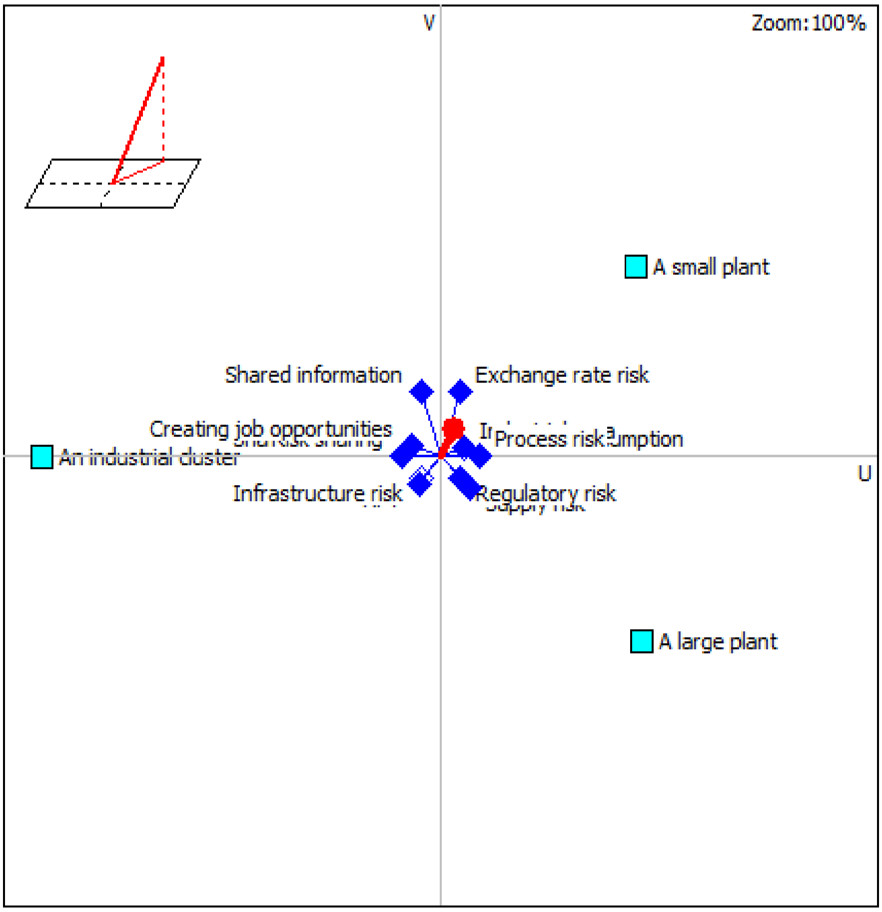
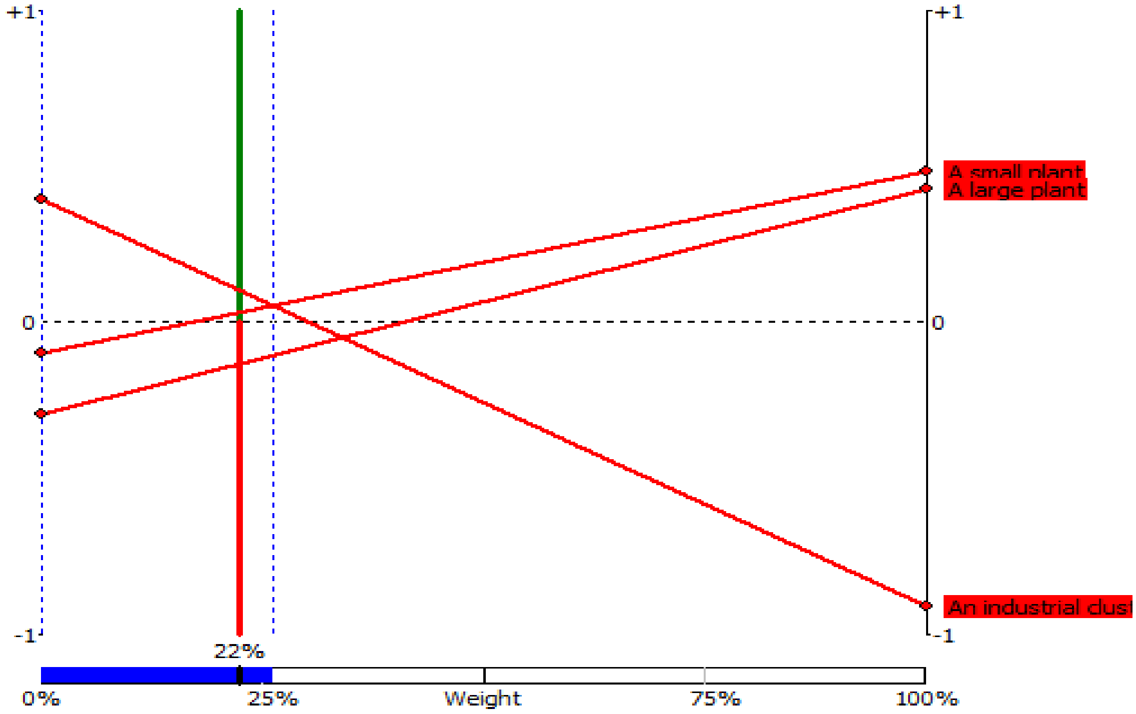


Figure 5-5: The GAIA plane to the PROMETHEE ranking

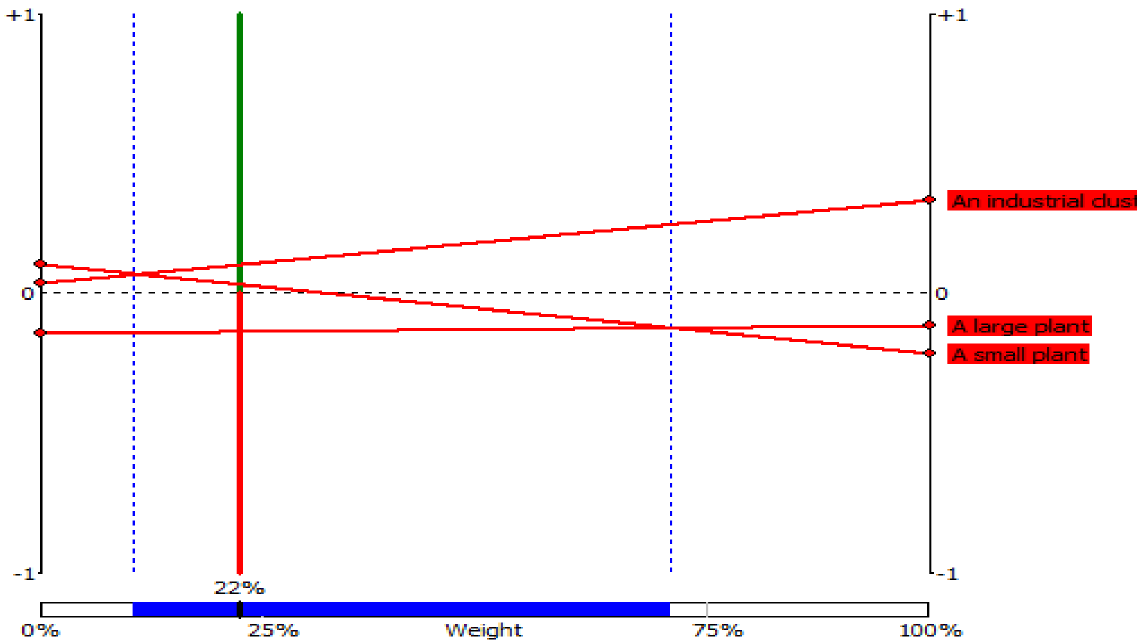
5.4.6 Sensitivity Analysis

A sensitivity analysis is an important process in MCDA as it provides further insight into decision problems ((Belton & Stewart, 2002). A sensitivity analysis can be used as a tool to explain possible inconsistencies in decision makers' judgment and to help them explore the implications of their judgment. Sensitivity analyses investigate how the result of a model changes with the addition of different input values. The result of the sensitivity analysis might be used to build and explore consequence models, support the elicitation of judgmental input, develop efficient computational algorithms, design experiments, make inferences, forecasts and decisions, explore and build consensus, build understanding and help decision makers to learn the significance of uncertainties in their data and models (French, 2003; French & Geldermann, 2005).

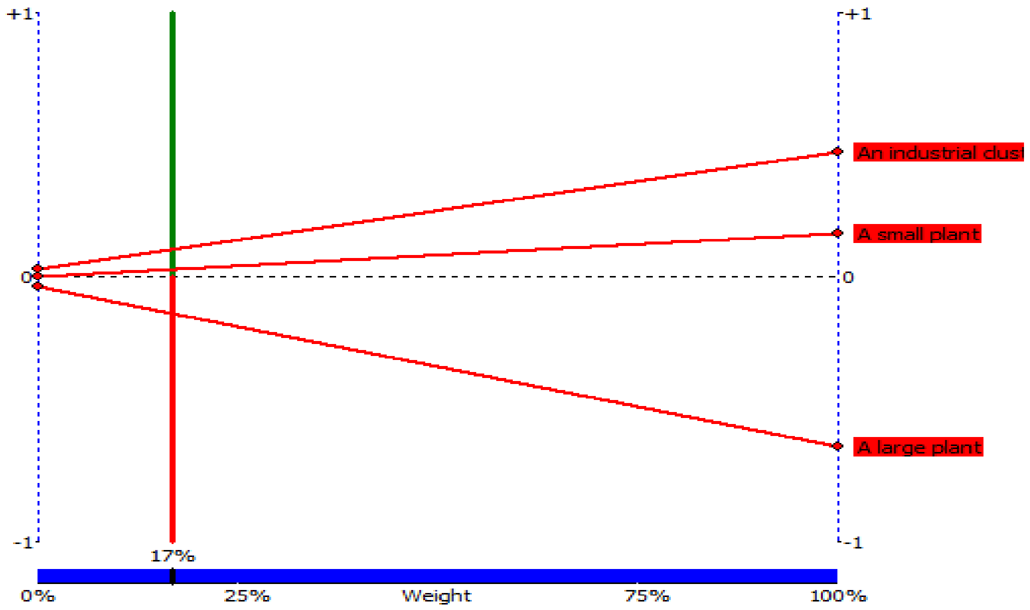
In PROMETHEE, sensitivity investigate how the Phi net (Φ_{net}) change as a function of the weight of a criterion. For environmental criteria, building a small plant will change from being the top choice if the weight is more than 25%. An industrial cluster is at the top of the PROMETHEE II ranking based on the economics criteria if the weight of each criterion is set to anywhere from 10 to 65%. However, industrial cluster is the highest ranking whenever the weight of the criterion is set to abide social perspectives. It can be seen that an industrial seaweed cluster is at the top ranking whenever the weight of the criterion is set to more than 30% (Figure 5-6).



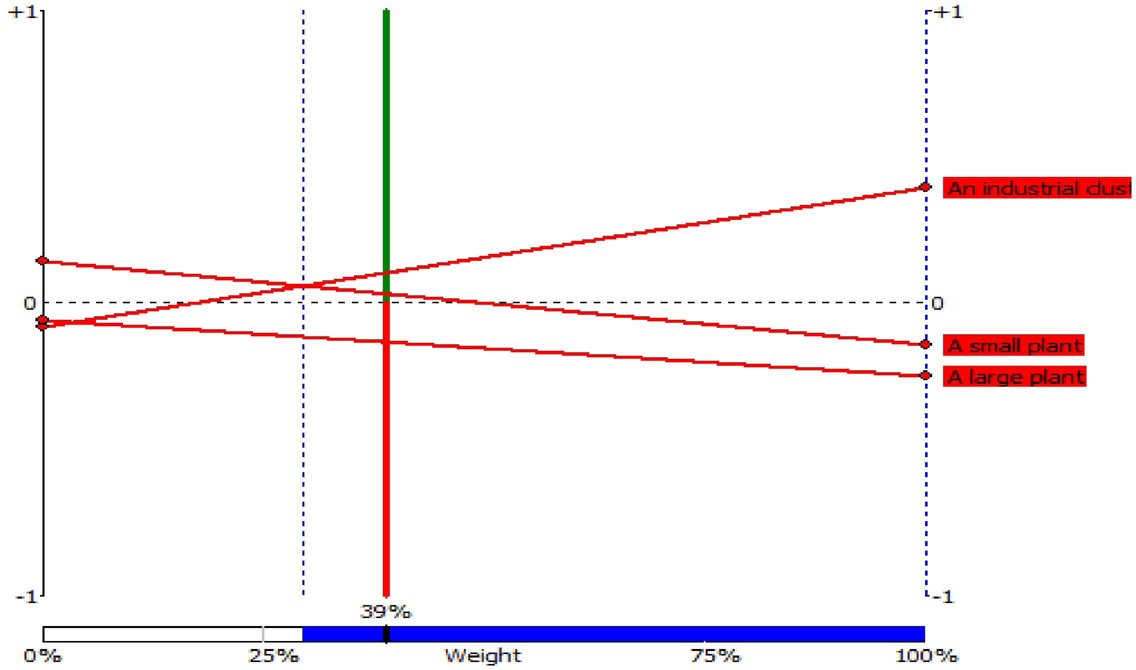
Sensitivity analysis regarding weight of environmental criteria



Sensitivity analysis regarding weight of economics criteria



Sensitivity analysis regarding weight of social criteria



Sensitivity analysis regarding weight of risk criteria

Figure 5-6: Sensitivity analysis regarding weight of environmental, economic, social and risk criteria

6 Conclusions and Outlook

The chapter critically reflects the developed assessment of supply chain risk in the seaweed industry in Indonesia. The limitations of the study provide some recommendations for future research, both theoretically and empirically.

6.1 Conclusions

This research contributes to the existing knowledge of supply chain risks by providing an empirical and theoretical framework on the specific product of seaweed. This research offers several noteworthy contributions for business administration in particular seaweed industry as a guidance of supply chain risk management. Specifically for seaweed producers, this study can be a reference as early warning of risks in a seaweed supply chain. In accordance with managing supply chain risks, there are four critical steps: supply chain flow identification, risk identification and categorization, risk assessment, and risk mitigation strategies. In this study, the triple bottom line of sustainability is considered as an important aspect of supply chain risk management.

Indonesia’s tropical climate and natural stock of seaweed are great opportunities for further development of seaweed industry. In terms of supply, Sulawesi Island, located in eastern Indonesia, is the largest region that produces both *Eucheuma* and *Gracilaria* seaweed in numerous locations, including South Sulawesi, Central Sulawesi and Southeast Sulawesi. The global demand for semi-refined carrageenan is increasing at a faster rate than other types of seaweed, such as alkali-treated *cottonii* and refined carrageenan. However, the global demand for agar is decreasing because 80% of total demand comes from the domestic market. Therefore, the global demand for *E. cottonii* is increasing at a more significant rate than *Gracilaria*.

The first critical step of supply chain risk assessment is supply chain mapping in order to depict the flow of materials, specifically from seaweed farmers to carrageenan and agar manufacturers. The key members of a seaweed supply chain in Indonesia can be classified into three main groups: seaweed suppliers, focal companies including carrageenan and agar companies, and consumers. The seaweed suppliers consist of seaweed farmers, local collectors, and large traders/exporters. The activities of most seaweed suppliers are very similar and typically include sun drying, packaging and transporting of seaweed. Local traders play an essential role in supporting farmers financially, as well as being important for technical information and market access. Producing refined carrageenan requires a substantial amount of electricity and water, while agar production demands larger quantities of wet seaweed.

The identification and categorization of seaweed supply chain risks in this study involved conducting an extensive literature review, as well as in-depth interviews with eight carrageenan companies, two agar companies, three large traders, two seaweed farmers, and seaweed experts from the Indonesian Institute of Science (LIPI) and the NGO, *Jasuda*.

Internal risks refer to risks within the company and include process and control risks. Risks relating to seaweed supply, moreover, include supply and demand risks. Sustainability factors, meanwhile, are grouped as external risks.

The risk assessment has shown that the low quality of raw dried seaweed is the most critical element in carrageenan supply chains. Agar supply chains, however, are more vulnerable to risks relating to yield uncertainty, scarcity of raw dried seaweed and waste water.

Sustainability and risk criteria are important aspects in formulating risk mitigation strategies. In this research, the assessment of the strategies used the Multi-Criteria Decision Analysis (MCDA) approach. The Preference Ranking Organization Method for Evaluation (PROMETHEE) method was selected as a suitable tool for this analysis including both monetary and non-monetary factors, in order to aid in the decision making process. The compared strategies to minimize seaweed supply chain risks include building a small scale seaweed processing facility, a large seaweed plant, and building a seaweed industrial cluster.

In the investigated case study a seaweed industrial cluster shows the greatest strengths in comparison to a small plant and a large company. However, a seaweed industrial cluster is more likely to adversely impact the environment due to large quantities of solid waste produced by the industrial cluster, which is greater than in the other alternatives. According to the sensitivity analysis, building a small plant is the first choice if a weight of less than 25% is related to environmental criteria. An industrial cluster is the top choice based on economic criteria if the weight is set from between 10 and 65%. An industrial cluster gets the highest ranking whenever the weight of social criteria is set. From the risk criteria, an industrial seaweed cluster is the top choice if the weight is set to more than 30%.

6.2 Outlook

This research has highlighted a number of topics which might be beneficial for further studies. In this research, data was collected from Indonesian based companies; therefore, the results are only valid for companies with a similar political, economic and geographic setting. Similar empirical research in other countries can be conducted to account for different country settings, such as China as the main global producer of carrageenan, or Chile as the largest producer of agar. It is of interest to evaluate risks in global seaweed supply chains in further research. Similar approaches might be taken to observe further processes downstream on the seaweed supply chain, for example with blended and dairy products. The research process presented in this study could also be transferred in other studies related to food supply chains.

Waste water and solid waste indicate environmental impacts of the seaweed industry. During the production process, water quantities presumably remain the same. The amount of waste water is assumed to correspond or equal to the amount of fresh water added to the production. Therefore, further studies related to evaluating the potential environmental impacts of the seaweed industry using the life cycle analysis (LCA) are necessary. Other potential studies can be conducted through combining the concept of supply chain risk and LCAs.

The risk assessment can be extended or combined with other methods to further describe the probability and the impact of adverse events. In this study, risk impact is assessed through a semi-quantitative analysis. Further research is required to determine the impact of supply chain risks on monetary values, for example through the evaluation of a cost-benefit analysis.

The criteria of risk mitigation strategies analyzed in this work were obtained from preexisting literature. Further work should aim to identify criteria by involving the affected stakeholders of the seaweed industry in Indonesia. Practical application of PROMETHEE approach can be conducted in a workshop with affected stakeholders.

Building a seaweed industrial cluster requires a strong commitment from all potential stakeholders. The key success factors of industrial clusters depend on infrastructure, institutional framework and government support in terms of laws, taxation and finance. The government plays an essential role in the development of a cluster. The government should provide market mechanisms and build the infrastructures (Kuchiki & Tsuji, 2005). Institutional criteria could be as important aspect in the industrial cluster. Therefore, further investigation aimed at determining the effectiveness of a seaweed industrial cluster is recommended. Another possible area of future research would be to investigate potential environmental impacts of an industrial cluster.

7 Summary

Seaweed supply chains, in particular carrageenan and agar products, are facing a dynamic business environment as a result of internal and external factors. The specific characteristics of seaweed product chains have led to an increase in supply chain risks. The concept of supply chain risk management is one of the proposed solutions to handle the problems. This research attempts to design a model of seaweed supply chain risk management in Indonesia through empirical research. The approach for development comprises identification, categorization, and assessment of possible risks within the seaweed supply chain; and evaluation of different risk mitigation strategies with MCDA. The exemplar application elucidates the general procedure. The research focuses on red commercial seaweeds, *Eucheuma cottonii* and *Gracilaria*, which produce carrageenan and agar.

This study proceeds in several steps. Initially, a general overview of seaweed farming, the seaweed industry, supply and demand of seaweed and its products: carrageenan and agar, is required to determine the objective of the study. The following steps describe seaweed supply chains in order to get a better understanding of the material and energy flow between the seaweed suppliers and seaweed manufacturers. Afterwards, risk identification and categorization is investigated to verify the causes and effects of the risk sources. The fourth step is risk assessment, assessing the risks in terms of the likelihood of occurrence and potential consequences on a risk map. Finally, the multi-criteria decision support approach, the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), is being applied for considering the various aspects of sustainability. In this way, economic, environmental, and social aspects can be integrated in the assessment of risk mitigation strategies.

The data were gathered using several approaches: field survey, documentary analysis and in-depth interviews. Field surveys were conducted in 2012 and 2013 in South Sulawesi (Makassar and Maros), East Java (Surabaya, Pasuruan, and Sidoarjo), West Java (Bogor and Bekasi), Banten (Cilegon), and West Nusa Tenggara (Mataram). Documentary analysis performed by researching documents from the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, the Indonesian Seaweed Association, and through desk research (journals, books, as well as information from public media). In-depth interviews were conducted to carrageenan and agar companies using questionnaires to identify the flow of material and energy of the carrageenan and agar supply chain; and assessment of the internal and external risks of the seaweed supply chain.

In Chapter 2, seaweed farming, seaweed industry, and supply and demand of red seaweed are explored. Seaweed farming centers for both *Eucheuma* and *Gracilaria* are located in eastern part of Indonesia, especially in Sulawesi Island. The cultivation methods depend on regional environments, such as the farmers of *Eucheuma* in South Sulawesi mostly use the long-line method. Seaweed industry in Indonesia is dominated by carrageenan companies about of 65%. The production of *Eucheuma* was

approximately seven to nine times higher than *Gracilaria* from 2007 to 2011. The global sales value of carrageenan is the highest (81%) amongst agar and alginates from 1999 to 2009.. Indonesia's export volume of carrageenan has changed dramatically from 2011 to 2012, with an increase of nearly 300%. Growth of carrageenan manufacturing seems to be the main driver of the increase in production. On the other hand, the export volume of agar from Indonesia has declined by 13%. Many factors have collectively influenced the export volume of agar because it is mostly consumed and distributed in Indonesia. However, Indonesia has also been part of the group of global exporters during this period.

In Chapter 3, the primary members of the seaweed supply chain in Indonesia having vertical collaboration can be distinguished as seaweed suppliers, seaweed manufacturers, and consumers. Seaweed suppliers comprise seaweed farmers; local collectors as both local and district middlemen; large traders or exporters. Seaweed manufactures consist of carrageenan and agar (seaweed by-products) companies. The primary members are supported by seedling suppliers, banking and/or financial institutions, cooperatives and transportation services. National governments, universities, the Indonesian Scientific Institute (LIPI), and other institutions also support influential members of the seaweed supply chain. The governmental departments that primarily support the sector are the Ministry of Marine Affairs and Fisheries, the Ministry of Industry, the Ministry of Trade, the Ministry of Cooperative and Small Medium Enterprises and the State Ministry for Accelerated Development of Disadvantaged Regions. Other associations support the seaweed farmers, large traders and/or exporters and seaweed manufacturers. Three associations that are responsible for supporting primary members are the Indonesian Seaweed Association or *Asosiasi Rumput Laut Indonesia* (ARLI), the Indonesian Seaweed Farmers and Industries Association or *Asosiasi Petani dan Pengusaha Rumput Laut Indonesia* (ASPPERLI), as well as the Indonesian Seaweed Industry Association or *Asosiasi Industri Rumput Laut Indonesia* (ASTRULI). These institutions assist seaweed farmers and seaweed industries to develop their business, such as financial grant, research and development related to seaweed products, and technical information.

Based on mass and energy flow management, wet seaweed for agar production is identified as the largest volume because it requires 89.62 kg of wet seaweed to produce 1 kg of agar. The production of RC requires the largest amount of electricity and water. To produce 1 kg of RC, 173.69 MJ of electricity and 0.31 m^3 of water are needed. For the purpose of this paper, waste water is assumed to have the same value as the water requirements for all production systems.

In Chapter 4, the sources of risk to a seaweed supply chain are categorized into two groups: internal and external risks. Further, the internal risks are classified into two categories: internal risks to the firm and external risks to the firm, but internal risks to the supply chain. Internal risks to the firm consists of processes and control risks; while the risks within the seaweed supply chains are comprised of supply and demand risks. Moreover, the external risks are risks outside of the companies and supply chains, which include financial, policy and infrastructure risks, social risks and environmental risks.

Based on the risk assesment, the most critical risk in a carrageenan supply chain is poor quality of raw dried seaweed. This finding may be explained that the companies received raw dried seaweed that does not comply with the standard requirements, such as the product having a moisture content of more than 35%. The critical risks in the agar supply chain are uncertain seaweed yields and scarcity of *Gracilaria,* as well as the negative impact of waste water on the environment. Other risks are categorized as marginal and negligible risks.

In Chapter 5, sustainability and risk aspects should be taken into consideration for mitigating risks in a seaweed supply chain. The decision making can be complex because of the trade-off between sustainability as well as risk criteria. Many criteria are in qualitative units of measurement which are very important in risk mitigation strategies. Therefore, the PROMETHEE approach as a tool in MCDA is applied for the decision making process of the mitigation strategies. The risks in a seaweed supply chain might be minimized by building a production plant near seaweed farming areas to improve quality control of raw dried seaweed. The proposed alternatives for mitigating seaweed supply chain risks in Indonesia are as follows: building a small seaweed manufacturing, a large seaweed manufacturing, and a seaweed industrial cluster. A case study is conducted with semi-refined carrageenan located in Takalar sub-province, South Sulawesi. Based on the calculation, building a seaweed industrial cluster is the greatest strength strategy to mitigate risks. However, a seaweed cluster can adversely affect the local environment.

In Chapter 6, conclusions and outlook for future research are provided. Similar empirical research can be conducted to account for different countries and others related agri-food products. Furthermore, combining the concept of supply chain risk and LCAs could be used. Practical application of PROMETHEE can be conducted in a workshop with affected stakeholders.

In this study, supply chain risk management is applied for the first time in seaweed industry as an important field in Indonesia. The comprehensive research of supply chain risk management is conducted to give a valuable insight for those who are interested in this concept. The critical steps for managing seaweed supply chain risks consist of identification of seaweed supply chains, identification and categorization of seaweed supply chain risks, assessment of the risks, and mitigation strategies to minimize the risks. In this work, the concept of supply chain risk management is developed which sustainability aspects (economic, environmental, and social criteria) were taken into account. The triple bottom line of sustainability is important factor in the steps of identification, assessment, and mitigation of seaweed supply chain risks.

8 Appendix

I. Questionnaire for Material and Energy Flow in Seaweed Industry

Production of carrageenan: Alkali-treated cottonii (ATC), semi-refined carrageenan (SRC) and refined carrageenan (RC)

The method for producing RC: A. Gel press b. Alcohol precipitation

I made the process of carrageenan and agar based on some literatures using gel press method. You could change the process according the actual process in your company. The initial input can be put as 1 kg raw dried seaweed (RDS)

No	Proses	Input	Output	Ratio	Energy
1	Washing and cleaning RDS	RDS = ……………….. kg	$RDS_{cleaned}$ = …… kg	For example 1 kg RDS need water 6 liter in this process. Therefore, the ratio is 1:6	Water = ……… liter
2	Alkali treatment	$RDS_{cleaned}$ = ………… kg KOH = ……………kg (if the firm use KOH). You can change the material	RDS_{alkali} = …….. .kg		Water = …. liter Electricity = …. Kwh Fuel = …..liter (please specify what kind of fuel that you use in the production)
3	Netralization	RDS_{alkali} = …………….kg	$RDS_{netralization}$= …..kg Liquid waste = m^3		Water = …… liter
4	Agitation	$RDS_{netralisasi}$=……….. kg	$RDS_{agitation}$ =……..kg		Electricity =
5	Extraction	$RDS_{agitation}$= ………..kg KOH :	$RDS_{extraction}$= ……..kg Liquid waste =		Water = . liter Electricity = …KwH Fuel =……… liter
6	Coarse filtration	$RDS_{ekstraksi}$ = ………..kg Filter aid =	Filtrate =………..kg Residue = ……..kg		Electricity = … KwH
7	Precipitation	Filtrate ……………..kg	$Filtrate_{precipitation}$ =		Electricity = .. KwH
8	Fine filtration	Filter aid = …………..kg	$Carrageenan_{fibre}$ =…..kg		Electricity = … KwH
9	Freezing	$Carrageenan_{fibre}$ = …..kg	$Carrageenan_{fibre}$ =…kg		Electricity = .. KwH
10	*Gel pressing*	$Carrageenan_{fibre}$ =……..kg	Gel = …………kg		Electricity = .. KwH
11	Drying	Gel = = ……………kg	$Carrageenan_{strip}$ = …………………..kg		Electricity = … KwH
12	Milling	$Carrageenan_{strip}$ =……..kg	$Carrageenan_{powder}$ = ………………kg		Electricity = .. KwH
13	Packaging	$Carrageenan_{powder}$ = ……..kg Packaging plastic = ……………gr	$RC_{finished}$ = …………………..kg		Electricity = .. KwH

II. Questionnaire of Risk Identification

Risk sources with their causes and effects of seaweed supply chains

No	Risk source	Causes	Effects
I.	**Internal risks to the firm**		
1.1 Process risk sources			
P.1	Failure in chemicals mixing		
P.2	Low quantity yields		
P.3	Machine breakdowns		
P.4	Low quality products		
1.2 Control risk sources			
C.1	Inadequate safety stock		
C.2	Inappropriate production scheduling		
C.3	Lack of collaborative planning between the focal company and seaweed suppliers		
II.	**Internal risks to the supply chain, but external risks to the firm**		
2.1 Supply risk sources			
S.1	Fluctuation of raw dried seaweed price		
S.2	Scarcity of raw dried seaweed		
S.3	Uncertain of seaweed yields		
S.4	Low quality of raw dried seaweed		
S.5	Failure in raw dried seaweed delivery		
S.6	Distance between seaweed farming and the companies is far		
2.2 Demand risk sources			
D.1	Demand uncertainty		
D.2	Product price volatility		
D.3	Customer switching		
III.	**External risk sources**		
3.1 Finance, policy and infrastructure risks			
E.1	Variability of government regulation		
E.2	Fluctuation of currency exchange rates		
E.3	Poor infrastructure		
E.4	Disturbance of electricity supply		
E.5	Scarcity of fresh water		
3.2 Social risks			
E.7	Low community acceptance		
E.8	Lack of employment opportunities		
Environmental risks			
E.9	Industrial seaweed wastewater negatively impacts the environment		
E.10	Seaweed solid wastes negatively impacts the environment		
E.11	Natural disasters: floods and earthquakes		

III. Questionnaire of Risk Assessment

The frequency and impacts of risk sources using Likert scale (7 points)

Scale	Likelihood of an adverse event(L)	Scale	Impact (I)
1	Never	1	Not relevant or never
2	Rarely, the probability is about 10%	2	Not significant
3	Occasionally, the probability is about 30%	3	Somewhat insignificant
4	Sometimes, the probability is about 50%	4	Neither significant or insignificant
5	Frequently, the is about 70%	5	Somewhat significant
6	Usually, the probability is about 90%	6	Significant
7	Every time	7	Very significant

No	Risk source	L/I	Choose the value based on your experiences						
			1	2	3	4	5	6	7
I.	**Internal risks to the firm**								
	a. Process risk assessment								
P.1	Failure in chemicals mixing	L							
		I							
P.2	Low quantity yields	L							
		I							
P.3	Machine breakdowns	L							
		I							
P.4	Low quality products	L							
		I							
1.2	**Control risk assessment**								
C.1	Inadequate safety stock	L							
		I							
C.2	Inappropriate production scheduling	L							
		I							
C.3	Lack of collaborative planning between the focal company and seaweed suppliers	L							
		I							
II.	**Internal risks to the supply chain, but external risks to the firm**								
2.1	**Supply risk**								
S.1	Fluctuation of raw dried seaweed price	L							
		I							
S.2	Scarcity of raw dried seaweed	L							
		I							
S.3	Uncertain of seaweed yields	L							
		I							
S.4	Low quality of raw dried seaweed	L							
		I							
S.5	Failure in raw dried seaweed delivery	L							
		I							
S.6	Distance between seaweed farming and the companies is far	L							
		I							
2.2	**Demand risk assessment**								
D.1	Demand uncertainty	L							
		I							
D.2	Product price volatility	L							
		I							
D.3	Customer switching	L							
		I							

External risks assessment									
E.1	Variability of government regulation	L							
		I							
E.2	Fluctuation of currency exchange rates	L							
		I							
E.3	Poor infrastructure	L							
		I							
E.4	Disturbance of electricity supply	L							
		I							
E.5	Scarcity of fresh water	L							
		I							
E.6	Low community acceptance	L							
		I							
E.7	Lack of employment opportunities	L							
		I							
E.8	Industrial seaweed wastewater negatively impacts the environment	L							
		I							
E.9	Seaweed solid wastes negatively impacts the environment	L							
		I							
E.10	Natural disasters: floods and earthquakes	L							
		I							

IV. Calculation of Net Present Value for A Seaweed Small Plant

Assumptions

Assumption	Unit measurement	Value
Economic life of the project	years	10
Working days	days per year	288
Price of product (SRC)	IDR/kg	120,000.00
Capacity	ton per year	125
Capacity	kg per month	10,416.67
Salvage value of building from the first value	%	50
Salvage value of land	%	100
Salvage value of machines & tools	%	10
Economic life of machines,tools, and transportation	years	10
Economic life of office tools	years	5
Maintenance cost	% per year	1
Discount factor	%	11.75%
Income tax	%	10.00
Debt Equity ratio	%	100%

Working capital is calculated due to operational cost during three months since the first year of production

Project is started in the 0 year and the first production in the first year

Type of cooperative Producer cooperative

Price of KOH : 10,000 IDR/kg

Price of RDS (*E.cottonii*) : 15,000 IDR/kg

Machines and Tools with the price in Million IDR

No.	Machine/tool	Unit measurement	Quantity	Price	Sub total
1	**Main machines & tools**				
	Water pump SANYO PDS 255A	unit	2	3.12	6.24
	Water tank Penguin 11,000 liter	unit	3	18.2	54.60
	Generator Honda SFT, 11.500 DXE, capa	unit	1	500.00	500.00
	Rotary washer	unit	1	50.00	50.00
	Stainless steel double jacket tank with mi:	unit	7	60	420.00
	KOH tank	unit	1	30.00	30.00
	Bak perendaman	unit	5	1	5.00
	Cutting machine of rds	unit	2	20	40.00
	Industrial tray dryer	unit	5	30	150.00
	Hammer mill	unit	2	30	60.00
	Flour sieve machines	unit	2	15	30.00
	Packaging machine	unit	1	8.5	8.50
	Total (1)				**1,354.34**
	Maintenance cost (1%) per year				**13.54**
2	**Supporting machines & tools**				
	Timbangan (weigher)	unit	5	1.3	6.50
	Turbine ventilator Ozvent	unit	3	0.7	2.10
	Diesel tank	unit	1	20	20.00
	Trolley	unit	8	1.5	12.00
	Exhaust fan	unit	5	1.5	7.50
	Fire safety	unit	5	0.75	3.75
	Laboratorium tools	package	1	150	150.00
	Hoe fork	unit	5	0.03	0.15
	Small basket	unit	10	0.08	0.80
	Big basket	unit	10	0.175	1.75
	Hose	unit	2	0.2	0.40
	Shovel	unit	3	0.03	0.09
	Table in the plant	unit	4	0.8	3.20
	Desktop computer for the plant	unit	1	4.3	4.30
	Total (2)				**212.54**
	Maintenance cost (1%) per year				2.13
	Total (1+2)				**1,566.88**
	Total maintenance cost (1%) per year				**15.67**

Office tools and equipment with the price in Million IDR

No	Component	Unit measurement	Quantity	Price	Sub Total
1	**Office tools**				
	Chair for general assembly,audit committee,election committee,board of directors (4) , sentr	unit	6	1.2	7.2
	Chair for staffs, secretary,Renzo SA	unit	13	0.8	10.4
	Tables for general assembly,audit committee, election committee, board of directors (4)	unit	6	2	12
	Tables for Supervisors,secretary	unit	13	1.5	19.5
	chair and tables for security	package	1	1	1
	Conference table Aditech Astro	Unit	1	5	5
	Conference chairs	Unit	10	0.4	4
	Sofa	unit	1	2	2
	Table sofa	unit	1	1	1
	Computer Acer pc desktop AMC 605	unit	19	4.3	81.7
	Toshiba Satellite L735-1131U,Core i3 2350M 2.3Ghz, 2GB DDR3, 640GB, DVDRW, Wifi, Bluetooth, Intel HD, Camera, 13.3″ WXGA, Win 7 Home Basic	unit	2	6.844	13.688
	EPSON printer LQ 310	unit	6	2.49	14.94
	LCD projector EPSON,EBX	unit	1	7.42	7.42
	Faximile Canon L170	unit	1	3.65	3.65
	Paper Schredder 836 C	unit	1	2.3	2.3
	Money counter Dsaiko 2108	unit	2	2.1	4.2
	Whiteboard	unit	2	0.5	1
	Flipchart	unit	2	0.65	1.3
	Calculator machine	unit	2	0.25	0.5
	Archive cupboards	unit	1	2.1	2.1
	Fillling cabinet	unit	19	0.65	12.35
	Sliding cupboards	unit	2	2	4
	Brankas Fire resistant type fb 60 SCA with alarm	unit	1	4.6	4.6
	Locker LION L556	unit	1	1.4	1.4
	TV21"	unit	1	2	2
	Telephone,panasonic KX TS820	unit	20	0.25	5
	Air conditioner 0.5 PK	unit	16	2.5	40
	Total (1)				**264.25**
	Maintenance cost (1%) per year				**2.64**
2	**Transportation**				
	Car for operational:managers (avanza)	unit	1	163	163
	Pick up STD T120SS	unit	2	83.5	167
	Motor bicycle	unit	2	15	30
	Total (2)				**360.00**
	Maintenance cost (1%) per year				**3.60**
	Total (1+2)				**624.25**
	Total maintenance cost (1%) per year				6.24

Investment with the price in Million IDR

	Component	Unit measurement	Volume	Price	Sub total
1	**Pre-invesment**				
	Legal aspect	package	1	1.00	1.00
	Total (1)				**1.00**
2	**Land and building**				
	Land	m2	1,800	1.00	1,800.00
	Building				
	Drying area	m2	75	0.15	11.25
	Office	m2	125	1.00	125.00
	Plant	m2	1,000	1.25	1,250.00
	Laboratory	m2	50	1.00	50.00
	Raw dried seaweed warehouse	m2	100	0.50	50.00
	Supporting materials warehous	m2	100	0.50	50.00
	Product warehouse	m2	100	0.50	50.00
	Workshop	m2	50	0.50	25.00
	Park area	m2	150	0.30	45.00
	Landscape	m2	50	0.35	17.50
	Sub total building		1,800		1,673.75
	Total (2)				**5,147.50**
	Maintenance cost (1%) per year				51.48
3	**Supporting facilities**				
	Water instalation	package	1	15.00	15.00
	Electricity instalation	package	1	15.00	15.00
	Waste and water treatment	package	1	75.00	75.00
	Telephone network instalation	package	1	1.00	1.00
	Total (3)				**106.00**
4	**Machines**	package	1	1,354.34	1,354.34
5	**Supporting machines and to**	package	1	212.54	212.54
6	**Office tools**	package	1	264.25	264.248
7	**Transportation**	package	1	360.00	360.000
	Total (1+2+3+4+5+6+7)				**7,445.628**
	Contingency 10%				**744.56**
	Total Investment				**8,190.19**

Working capital with the price in Million IDR

No	Component	Quantity	Unit measurement	Price	Sub Total/month	Sub total/year
Fix cost						
1	**Salary**					
	General Assembly	1.00	person	10.00	10.00	120.00
	Audit and Election committee	1.00	person	8.00	8.00	96.00
	Board of Directors	4.00	person	7.00	28.00	336.00
	-Director of Production					
	- Director of General and Human Resources					
	- Director of Finance and Administration					
	- Director of Marketing					
	Secretary	1.00	person	6.00	6.00	72.00
	Staff	12.00	person	5.00	60.00	720.00
	- Quality : raw material & product	2.00				
	- Process : production,logistics,maintena	2.00				
	- Research and development	2.00				
	- Education and training	2.00				
	- Human resources development	1.00				
	- Treasurer	1.00				
	- Administration	1.00				
	- Promotion and Distribution	1.00				
	Production staff	10.00	person	2.50	25.00	300.00
	Driver	1.00	person	2.00	2.00	24.00
	Office boy	1.00	person	1.50	1.50	18.00
	Security	2.00	person	2.00	4.00	48.00
	Total (1)	**33.00**	person		**144.50**	**1,734.00**
2	**Maintenance cost**				**6.12**	**73.39**
			Total fix cost per month		**150.62**	
			Total fix cost per year			**1,807.39**
Variable cost						
1	**Raw materials & supporting materials**					
	RDS	43,125.00	kg/month	0.015	625.31	7,503.75
	KOH	2,083.33	kg/month	0.016	33.33	400.00
	Packaging	417.00	unit/month	0.004	1.67	20.02
	Total (1)				**660.31**	**7,923.77**
2	**Fuel and heating oil**					
	Fuel	3,645.83	kg/month	0.0075	27.34	328.12
	Heating oil	10	m3/month	0.006	0.06	0.72
	Total (2)				**27.40**	**328.84**
3	**Electricity**					
	Electricity for production	46,875.00	KwH	0.001075	50.39	604.69
	Electricity for non production (20%)	9,375.00	KwH	0.001075	10.08	120.94
	Total (3)				**60.47**	**725.63**
4	**Water**					
	Water for production	520.83	m3/month	0.0018	0.94	11.25
	Water for non production (20%)	104.17	m3/month	0.0018	0.19	2.25
	Total (4)				**1.12**	**13.50**
5	**Office & administration supplies**					
	Office supplies	1	package	0.5	0.5	6.00
	Telephone	1	package	5	5	60.00
	Kitchen supply	1	package	0.5	0.5	6.00
	Fuel for operational car	50	m3	0.0085	0.425	5.10
	Promotion activities	1	package	1	1	12.00
	Distribution	1	package	8	8	96.00
	Total (5)				**15.425**	**185.10**
			Total variable cost per month		**764.74**	
			Total variable cost per year			**9,176.83**
		Total operational cost per month			**915.35**	
		Total operational cost per year				**10,984.22**

Installment loan in Million IDR

Year	Total credit	Main installment	Interest rate 11.75%	Installment loan
0	10,859.17			
1	10,859.17	2,171.83	1,275.95	3,447.79
2	8,687.34	2,171.83	1,020.76	3,192.60
3	6,515.50	2,171.83	765.57	2,937.41
4	4,343.67	2,171.83	510.38	2,682.22
5	2,171.83	2,171.83	255.19	2,427.03
			3,827.86	**14,687.03**

Salvage value in Million IDR

No	Type	Initial value	Salvage value	Salvage value	Economic life	Depreciation per year
1	Land	1,800.00	1	1,800.00	-	-
2	Building	-	0.5	-	20	0.000
3	Machines & Tools	1,566.88	0.1	156.69	10	141.019
4	Supporting facility	106.00	0.1	10.60	10	9.540
5	Office tools	264.248	0.1	26.42	5	47.565
6	Transportation	360	0.1	36.00	10	32.400
	Total			**2,029.71**		**230.524**

Operational costs

No	Component	Year									
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
1	**Fix cost**										
	Salary	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00	1,734.00
	Maintenance	73.39	73.39	73.39	73.39	73.39	73.39	73.39	73.39	73.39	73.39
	Depreciation	230.524	230.524	230.524	230.524	230.524	230.524	230.524	230.524	230.524	230.524
	Interest rate	1,275.95	1,020.76	765.57	510.38	255.19					
	Total fix cost	**3,313.86**	**3,058.67**	**2,803.48**	**2,548.29**	**2,293.10**	**2,037.91**	**2,037.91**	**2,037.91**	**2,037.91**	**2,037.91**
2	**Variable cost**										
	Raw materials & supporting	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77	7,923.77
	Fuel	328.84	328.84	328.84	328.84	328.84	328.84	328.84	328.84	328.84	328.84
	Electricity	725.63	725.63	725.63	725.63	725.63	725.63	725.63	725.63	725.63	725.63
	Water	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50	13.50
	Office and administration supplies	185.10	185.10	185.10	185.10	185.10	185.10	185.10	185.10	185.10	185.10
	Total variable cost	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83
3	**Operational cost**	**12,490.70**	**12,235.51**	**11,980.32**	**11,725.13**	**11,469.94**	**11,214.75**	**11,214.75**	**11,214.75**	**11,214.75**	**11,214.75**

Production

Year	Production per year (kg)	Fix cost per year	Variable cost per year	Cost per unit	Price of SRC (Million IDR/kg)	Profit (%)	Revenue (Million IDR)	BEP (Million IDR)	BEP (kg)
1	125,000	3,313.86	9,176.83	0.100	0.120	20.09	15,000	19,809.47	165,078.93
2	125,000	3,058.67	9,176.83	0.098	0.120	22.59	15,000	16,596.21	138,301.72
3	125,000	2,803.48	9,176.83	0.096	0.120	25.21	15,000	13,926.04	116,050.34
4	125,000	2,548.29	9,176.83	0.094	0.120	27.93	15,000	11,672.01	97,266.78
5	125,000	2,293.10	9,176.83	0.092	0.120	30.78	15,000	9,743.88	81,198.97
6	125,000	2,037.91	9,176.83	0.090	0.120	33.75	15,000	8,075.72	67,297.65
7	125,000	2,037.91	9,176.83	0.090	0.120	33.75	15,000	8,075.72	67,297.65
8	125,000	2,037.91	9,176.83	0.090	0.120	33.75	15,000	8,075.72	67,297.65
9	125,000	2,037.91	9,176.83	0.090	0.120	33.75	15,000	8,075.72	67,297.65
10	125,000	2,037.91	9,176.83	0.090	0.120	33.75	15,000	8,075.72	67,297.65

Benefit cost in Million IDR

Component	Year									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
A. Revenue										
Product selling	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00	15,000.00
Total revenue	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**	**15,000.00**
B.Cost										
Fix cost	3,313.86	3,058.67	2,803.48	2,548.29	2,293.10	2,037.91	2,037.91	2,037.91	2,037.91	2,037.91
Variable cost	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83	9,176.83
Total cost	**12,490.70**	**12,235.51**	**11,980.32**	**11,725.13**	**11,469.94**	**11,214.75**	**11,214.75**	**11,214.75**	**11,214.75**	**11,214.75**
EBIT (Earnings before interest and tax)	**2,509.30**	**2,764.49**	**3,019.68**	**3,274.87**	**3,530.06**	**3,785.25**	**3,785.25**	**3,785.25**	**3,785.25**	**3,785.25**
Income tax (10%)	250.93	276.45	301.97	327.49	353.01	378.53	378.53	378.53	378.53	378.53
Net benefit/cost	**2,258.37**	**2,488.04**	**2,717.71**	**2,947.39**	**3,177.06**	**3,406.73**	**3,406.73**	**3,406.73**	**3,406.73**	**3,406.73**

Cash flow in Million IDR

No	Component	Year										
		0	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
A	**Inflow cash**											
	Net benefit /cost		2,258.37	2,488.04	2,717.71	2,947.39	3,177.06	3,406.73	3,406.73	3,406.73	3,406.73	3,406.73
	Salvage value						26.42					2,029.71
	Return on working capital											2,668.98
	Loan	10,859.17										
	Total inflow cash	**10,859.17**	**2,258.37**	**2,488.04**	**2,717.71**	**2,947.39**	**3,203.48**	**3,406.73**	**3,406.73**	**3,406.73**	**3,406.73**	**8,105.43**
B	**Outflow cash**											
	Investment	10,859.17						6.24				
	Installment loan		2,171.83	2,171.83	2,171.83	2,171.83	2,171.83					
	Total outflow cash	10,859.17	2,171.83	2,171.83	2,171.83	2,171.83	2,171.83	6.24	-	-	-	-
C	**Net cash flow**	**0**	**86.54**	**316.21**	**545.88**	**775.55**	**1,031.65**	**3,400.49**	**3,406.73**	**3,406.73**	**3,406.73**	**8,105.43**
D	**Cash in the beginning of the year**	**0**	**0**	**86.54**	**402.75**	**948.63**	**1,724.18**	**2,755.82**	**6,156.31**	**9,563.04**	**12,969.77**	**16,376.50**
E	**Cash in the end of the year**	**0**	**86.54**	**402.75**	**948.63**	**1,724.18**	**2,755.82**	**6,156.31**	**9,563.04**	**12,969.77**	**16,376.50**	**24,481.93**

Net Present Value

Year	Net cash flow	Accumulation	Discount Factor (%)	Present value	Cummulative of present value
0	(10,859.17)	(10,859.17)	1.00	(10,859.17)	(10,859.17)
1	86.54	(10,772.64)	0.90	77.96	(10,781.21)
2	316.21	(10,456.43)	0.81	256.64	(10,524.57)
3	545.88	(9,910.55)	0.73	399.14	(10,125.43)
4	775.55	(9,135.00)	0.66	510.88	(9,614.55)
5	1,031.65	(8,103.35)	0.59	612.23	(9,002.32)
6	3,400.49	(4,702.86)	0.53	1,818.04	(7,184.28)
7	3,406.73	(1,296.13)	0.48	1,640.88	(5,543.40)
8	3,406.73	2,110.60	0.43	1,478.27	(4,065.13)
9	3,406.73	5,517.33	0.39	1,331.77	(2,733.35)
10	8,105.43	13,622.75	0.35	2,854.61	**121.25**
			NPV	**121.25**	

Calculation of Net present value for a seaweed large plant

Assumptions

Assumption	Unit measurement	Value
Economic life of the project	years	10
Working days	days per year	288
Price of product (SRC)	IDR/kg	120,000.00
Capacity	ton per year	500
Capacity	kg per month	41,666.67
Rendemen produk	%	25
Salvage value of building from the first value	%	50
Salvage value of land	%	100
Salvage value of machines & tools	%	10
Economic life of machines,tools, and transportation	years	10
Economic life of office tools	years	5
Maintenance cost	% per year	1
Discount factor	%	11%
Income tax	%	28.00
Debt Equity ratio	%	100%
Working capital is calculated due to operational cost during three monts since the first year of production		
Project is started in the 0 year and the first production in the first year		
Price of KOH	IDR/kg	10,000.00
Price of RDS (E.cottonii)	IDR/kg	15,000.00

Machines and Tools

No.	Machine/tool	Unit measurement	Quantity	Price	Sub total
1	**Main machines & tools**				
	Water pump SANYO PDS 255A	unit	8	3.12	24.96
	Water tank Penguin 11,000 liter	unit	10	18.2	182.00
	Diesel generator set,CAT C15 500KW	unit	1	1,000.00	1,000.00
	Rotary washer	unit	4	50.00	200.00
	Stainless steel double jacket tank with mixer	unit	30	60	1,800.00
	KOH tank	unit	4	30.00	120.00
	Bak perendaman	unit	20	2	40.00
	Cutting machine of rds	unit	5	15	75.00
	Industrial tray dryer	unit	20	30	600.00
	Hammer mill	unit	10	30	300.00
	Flour sieve machines	unit	5	15	75.00
	Packaging machines	unit	4	8.5	34.00
	Total (1)				**4,450.96**
	Maintenance cost (1%) per year				**44.51**
2	**Supporting machines & tools**				
	Timbangan (weigher)	unit	20	1.3	26.00
	Turbine ventilator Ozvent	unit	10	0.7	7.00
	Diesel tank	unit	1	20	20.00
	Oil circulation pump	unit	1	35	35.00
	Trolley	unit	20	1.5	30.00
	Forklift	unit	2	80	160.00
	Exhaust fan	unit	20	1.5	30.00
	Fire safety	unit	15	0.75	11.25
	Laboratorium tools	package	1	250	250.00
	Hoe fork	unit	20	0.03	0.60
	Small basket	unit	30	0.08	2.40
	Big basket	unit	30	0.175	5.25
	Hose	unit	5	0.2	1.00
	Shovel	unit	20	0.03	0.60
	Table in the plant	unit	10	1.2	12.00
	Desktop computer for the plant	unit	2	4.3	8.60
	Total (2)				**599.70**
	Maintenance cost (1%) per year				6.00
	Total (1+2)				**5,050.66**
	Total maintenance cost (1%) per year				**50.51**

Office tools and equipment with the price in Million IDR

No	Component	Satuan	Volume	Price	Sub Total
1	**Office tools**				
	Chair for CEO & managers , sentra SC 105	unit	7	1.2	8.4
	Chair for supervisors, secretary,Sentra SC 605	unit	12	0.8	9.6
	Tables for CEO & managers	unit	7	2	14
	Tables for Supervisors,secretary	unit	12	1.5	18
	Chairs for staffs	unit	28	0.6	16.8
	Tables for staffs	unit	28	0.5	14
	Chairs and tables for security	package	1	3	3
	Conference table Modera BCT 315	Unit	1	7.3	7.3
	Conference chairs	Unit	10	0.6	6
	Sofa	unit	1	2.5	2.5
	Table sofa	unit	1	1	1
	Computer Acer pc desktop AMC 605	unit	47	4.3	202.1
	Toshiba Satellite L735-1131U,Core i3 2350M 2.3Ghz, 2GB DDR3, 640GB, DVDRW, Wifi, Bluetooth, Intel HD, Camera, 13.3″ WXGA, Win 7 Home Basic	unit	7	6.844	47.908
	EPSON printer LQ 310	unit	30	2.49	74.7
	LCD projector EPSON, EBX 24	unit	2	7.42	14.84
	Faximile Canon L170	unit	2	3.65	7.3
	Paper Schredder 836 C	unit	1	2.3	2.3
	Money counter Dsaiko 2108	unit	4	2.1	8.4
	Whiteboard	unit	3	0.5	1.5
	Flipchart	unit	3	0.65	1.95
	Calculator machine	unit	4	0.25	1
	Archive cupboards	unit	4	2.1	8.4
	Fillling cabinet	unit	47	0.65	30.55
	Sliding cupboards	unit	18	2	36
	Brankas Fire resistant type fb 60 SCA with alarm	unit	2	4.6	9.2
	Locker LION L556	unit	2	1.4	2.8
	TV21"	unit	1	2	2
	Telephone,panasonic KX TS820	unit	47	0.25	11.75
	Air conditioner 0.5 PK	unit	25	2.5	62.5
	Total (1)				**625.80**
	Maintenance cost (1%) per year				**6.26**
2	**Transportation**				
	Car for CEO (Innova, New EMT Diesel)	unit	1	264.6	264.6
	Car for operational:managers (avanza)	unit	2	163	326
	Pick up STD T120SS	unit	3	83.5	250.5
	Truck colt diesel FE 73 (4x2)M/T 110 PS	unit	1	216	216
	Motor bicycle	unit	2	15	30
	Total (2)				**1,087.10**
	Maintenance cost (1%) per year				**10.87**
	Total (1+2)				**1,712.90**
	Total maintenance cost (1%) per year				17.13

Investment in Million IDR

No.	Component	Unit measurement	Volume	Price	Sub total
1	**Pre-invesment**				
	Legal aspect	package	1	62.50	62.50
	Total (1)				**62.50**
2	**Land and building**				
	Land	m2	10,000	1.00	10,000.00
	Building				
	Drying area	m2	300	0.15	45.00
	Office	m2	500	1.00	500.00
	Plant	m2	6,000	1.25	7,500.00
	Laboratory	m2	200	1.00	200.00
	Raw dried seaweed warehouse	m2	700	0.50	350.00
	Supporting materials warehouse	m2	500	0.50	250.00
	Product warehouse	m2	500	0.50	250.00
	Workshop	m2	300	0.50	150.00
	Park area	m2	700	0.30	210.00
	Landscape	m2	300	0.35	105.00
	Sub total building		10,000		9,560.00
	Total (2)				**19,560.00**
	Maintenance cost (1%) per year				195.60
3	**Supporting facilities**				
	Water instalation	package	1	40.00	40.00
	Electricity instalation	package	1	25.00	25.00
	Waste & water treatment	package	1	250.00	250.00
	Telephone network instalation	package	1	5.00	5.00
	Total (3)				**320.00**
4	**Machines**	package	1	4,450.96	4,450.96
5	**Supporting machines and tools**	package	1	599.70	599.70
6	**Office tools**	package	1	625.80	625.798
7	**Transportation**	package	1	1,087.10	1,087.100
	Total (1+2+3+4+5+6+7)				**26,706.058**
	Contingency 10%				**2,670.61**
	Total Investment				**29,376.66**

Working capital

No	Component	Quantity	Unit measurement	Price	Sub Total/month	Sub total/year
Fix cost						
1	**Salary**					
	Commisioner	1.00	person	15.00	15.00	180.00
	CEO	1.00	person	20.00	20.00	240.00
	Managers	5.00	person	12.50	62.50	750.00
	-Manager of Production					
	- Manager of General and Human Resources					
	- Manager of Finance and Administration					
	- Manager of Marketing					
	- Manager of Research and Development					
	Supervisors	11.00	person	8.00	88.00	1,056.00
	- Quality					
	- Process					
	- Maintenance					
	- Public relation					
	- Human resources					
	- Finance					
	- Administration					
	- Promotion					
	- Distribution					
	- Product development					
	- Marketing research					
	Executive secretary	1.00	person	6.00	6.00	72.00
	Staff	28.00	person	4.00	112.00	1,344.00
	- Quality : raw material & product	4.00				
	- Process : production,logistics	4.00				
	- Maintenance	2.00				
	- Public relation	2.00				
	- Human resources: recruitment, carreer planning	4.00				
	- Finance	2.00				
	- Administration	2.00				
	- Promotion	2.00				
	- Distribution	2.00				
	- Product development	2.00				
	- Marketing research	2.00				
	Production staff	30.00	person	2.50	75.00	900.00
	Driver	2.00	person	2.00	4.00	48.00
	Office boy	4.00	person	1.50	6.00	72.00
	Security	6.00	person	2.00	12.00	144.00
	Total (1)	**89.00**	person		**400.50**	**4,806.00**
2	**Maintenance cost**				**21.94**	**263.24**
			Total fix cost per month		**422.44**	
			Total fix cost per year			**5,069.24**
Variable cost						
1	**Raw materials & supporting materials**					
	Raw dried seaweed	172,552	kg/month	0.015	2,588.28	31,059.37
	Potassium hydroxide	8,333.33	kg/month	0.016	133.33	1,600.00
	Packaging	1,667	unit/month	0.004	6.67	80.00
	Total (1)				**2,728.28**	**32,739.38**
2	**Fuel and heating oil**					
	Fuel	14,583.33	kg/month	0.0075	109.37	1,312.50
	Heating oil	150	m3/day	0.006	0.9	10.80
	Total (2)				**110.27**	**1,323.30**
3	**Electricity**					
	Electricity for production	187,515.80	KwH/month	0.001075	201.58	2,418.95
	Electricity for non production (20%)	37,503.16	KwH/month	0.001075	40.32	483.79
	Total (3)				**241.90**	**2,902.74**
4	**Water**					
	Water for production	2,219.84	m3/month	0.0018	4.00	47.95
	Water for non production (20%)	443.97	m3/month	0.0018	0.80	9.59
	Total (4)				**4.79**	**57.54**
5	**Office & administration supplies**					
	Office supplies	1	package	1.5	1.5	18.00
	Telephone	1	package	10	10	120.00
	Kitchen supply	1	package	1	1	12.00
	Fuel for operational car	500	m3	0.0085	4.25	51.00
	Promotion activities	1	package	20	20	240.00
	Distribution	1	package	20	20	240.00
	Total (5)				**56.75**	**681.00**
			Total variable cost per month		**3,142.00**	
			Total variable cost per year			**37,703.96**
		Total operational cost per month			**3,564.43**	
		Total operational cost per year				**42,773.19**

Installment loan in Million IDR

Year	Total Credit	Main installment	Interest rate 11%	Installment loan
0	39,776.37			
1	39,776.37	7,955.27	4,375.40	12,330.67
2	31,821.09	7,955.27	3,500.32	11,455.59
3	23,865.82	7,955.27	2,625.24	10,580.51
4	15,910.55	7,955.27	1,750.16	9,705.43
5	7,955.27	7,955.27	875.08	8,830.35
			13,126.20	**52,902.57**

Salvage value

No	Type	Initial value	Salvage value	Salvage value	Economic life (years)	Depreciation per year
1	Land	10,000.00	1	10,000.00	-	-
2	Building	9,560.00	0.5	4,780.00	20	239.000
3	Machines & Tools	5,050.66	0.1	505.07	10	454.559
4	Supporting facility	320.00	0.1	32.00	10	28.800
5	Office tools	625.798	0.1	62.58	5	112.644
6	Transportation	1087.1	0.1	108.71	10	97.839
	Total			**15,488.36**		**932.842**

Operational cost in Million IDR

Component	Year									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Fix cost										
Salary	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00	4,806.00
Maintenance	263.24	263.24	263.24	263.24	263.24	263.24	263.24	263.24	263.24	263.24
Depreciation	932.842	932.842	932.842	932.842	932.842	932.842	932.842	932.842	932.842	932.842
Interest rate	4,375.40	3,500.32	2,625.24	1,750.16	875.08					
Total fix cost	**10,377.48**	**9,502.40**	**8,627.32**	**7,752.24**	**6,877.16**	**6,002.08**	**6,002.08**	**6,002.08**	**6,002.08**	**6,002.08**
Variable cost										
Raw materials & supporting	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38	32,739.38
Fuel	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30	1,323.30
Electricity	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74	2,902.74
Water	57.54	57.54	57.54	57.54	57.54	57.54	57.54	57.54	57.54	57.54
Office and administration supplies	681.00	681.00	681.00	681.00	681.00	681.00	681.00	681.00	681.00	681.00
Total variable cost	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96
Operational cost	**48,081.44**	**47,206.36**	**46,331.28**	**45,456.20**	**44,581.12**	**43,706.04**	**43,706.04**	**43,706.04**	**43,706.04**	**43,706.04**

Production

Year	Production per year	Fix cost per year	Variable cost per year	Cost per unit	Price of SRC (Million IDR/kg)	Profit (%)	Revenue (Million IDR)	BEP (Million IDR)	BEP (kg)
1	500,000	10,377.48	37,703.96	0.096	0.120	24.79	60,000	52,241.92	435,349.35
2	500,000	9,502.40	37,703.96	0.094	0.120	27.10	60,000	44,564.62	371,371.83
3	500,000	8,627.32	37,703.96	0.093	0.120	29.50	60,000	37,870.33	315,586.07
4	500,000	7,752.24	37,703.96	0.091	0.120	32.00	60,000	31,981.61	266,513.41
5	500,000	6,877.16	37,703.96	0.089	0.120	34.59	60,000	26,761.30	223,010.87
6	500,000	6,002.08	37,703.96	0.087	0.120	37.28	60,000	22,101.72	184,181.01
7	500,000	6,002.08	37,703.96	0.087	0.120	37.28	60,000	22,101.72	184,181.01
8	500,000	6,002.08	37,703.96	0.087	0.120	37.28	60,000	22,101.72	184,181.01
9	500,000	6,002.08	37,703.96	0.087	0.120	37.28	60,000	22,101.72	184,181.01
10	500,000	6,002.08	37,703.96	0.087	0.120	37.28	60,000	22,101.72	184,181.01

Benefit cost

Component	Year									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
A. Revenue										
Product selling	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00	60,000.00
Total revenue	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**	**60,000.00**
B.Cost										
Fix cost	10,377.48	9,502.40	8,627.32	7,752.24	6,877.16	6,002.08	6,002.08	6,002.08	6,002.08	6,002.08
Variable cost	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96	37,703.96
Total cost	**48,081.44**	**47,206.36**	**46,331.28**	**45,456.20**	**44,581.12**	**43,706.04**	**43,706.04**	**43,706.04**	**43,706.04**	**43,706.04**
EBIT (Earnings before interest and tax)	**11,918.56**	**12,793.64**	**13,668.72**	**14,543.80**	**15,418.88**	**16,293.96**	**16,293.96**	**16,293.96**	**16,293.96**	**16,293.96**
Income tax (28%)	3,337.20	3,582.22	3,827.24	4,072.27	4,317.29	4,562.31	4,562.31	4,562.31	4,562.31	4,562.31
Net benefit/cost	**8,581.37**	**9,211.42**	**9,841.48**	**10,471.54**	**11,101.60**	**11,731.65**	**11,731.65**	**11,731.65**	**11,731.65**	**11,731.65**

Cash flow

No	Component	Year										
		0	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
A	**Inflow cash**											
	Net benefit /cost		8,581.37	9,211.42	9,841.48	10,471.54	11,101.60	11,731.65	11,731.65	11,731.65	11,731.65	11,731.65
	Salvage value						62.58					15,488.36
	Return on working capital											10,399.70
	Loan	39,776.37										
	Total inflow cash	**39,776.37**	**8,581.37**	**9,211.42**	**9,841.48**	**10,471.54**	**11,164.18**	**11,731.65**	**11,731.65**	**11,731.65**	**11,731.65**	**37,619.71**
B	**Outflow cash**											
	Investment	39,776.37						17.13				
	Installment loan		7,955.27	7,955.27	7,955.27	7,955.27	7,955.27					
	Total outflow cash	39,776.37	7,955.27	7,955.27	7,955.27	7,955.27	7,955.27	17.13	-	-	-	-
C	**Net cash flow**	**0**	**626.09**	**1,256.15**	**1,886.21**	**2,516.27**	**3,208.90**	**11,714.53**	**11,731.65**	**11,731.65**	**11,731.65**	**37,619.71**
D	**Cash in the beginning of the year**	**0**	**0**	**626.09**	**1,882.24**	**3,768.45**	**6,284.72**	**9,493.62**	**21,208.14**	**32,939.80**	**44,671.45**	**56,403.11**
E	**Cash in the end of the year**	**0**	**626.09**	**1,882.24**	**3,768.45**	**6,284.72**	**9,493.62**	**21,208.14**	**32,939.80**	**44,671.45**	**56,403.11**	**94,022.82**

Net Present Value

Year	Net cash flow	Accumulation	Discount Factor (%)	Present value	Cummulative of present value
0	(39,776.37)	(39,776.37)	1.00	(39,776.37)	(39,776.37)
1	626.09	(39,150.27)	0.90	564.05	(39,212.32)
2	1,256.15	(37,894.12)	0.81	1,019.52	(38,192.80)
3	1,886.21	(36,007.92)	0.73	1,379.18	(36,813.62)
4	2,516.27	(33,491.65)	0.66	1,657.54	(35,156.08)
5	3,208.90	(30,282.75)	0.59	1,904.33	(33,251.75)
6	11,714.53	(18,568.22)	0.53	6,263.06	(26,988.69)
7	11,731.65	(6,836.57)	0.48	5,650.65	(21,338.04)
8	11,731.65	4,895.09	0.43	5,090.68	(16,247.36)
9	11,731.65	16,626.74	0.39	4,586.19	(11,661.17)
10	37,619.71	54,246.45	0.35	13,249.08	**1,587.91**
			NPV	**1,587.91**	

9 References

Adnan, H., & Porse, H. (1987). Culture of Eucheuma cottonii and Eucheuma spinosum in Indonesia. In M. A. Ragan & C. J. Bird (Eds.), *Twelfth International Seaweed Symposium* (pp. 355–358). Dordrecht: Springer Netherlands.

Al-Shemmeri, T., Al-Kloub, B., & Pearman, A. (1997). Model choice in multicriteria decision aid. *European Journal of Operational Research, 97*(3), 550–560. doi:10.1016/S0377-2217(96)00277-9

Amirjabbari, B., & Bhuiyan, N. (2014). Determining supply chain safety stock level and location. *Journal of Industrial Engineering and Management, 10*(1). doi:10.3926/jiem.543

Anand, G., & Kodali, R. (2008). Selection of lean manufacturing systems using the PROMETHEE. *Journal of Modelling in Management, 3*(1), 40–70. doi:10.1108/17465660810860372

Anggadiredja, J. T., Zatnika, A., Purwoto, H., & Istini, S. (2006). *Rumput laut: Pembudidayaan, pengolahan, & pemasaran komoditas perikanan potensial*. Depok: Penebar Swadaya.

Anisuzzaman, S. M., Bono, A., Samiran, S., Ariffin, B., & Farm, Y. Y. (2013). Influence of Potassium Hydroxide Concentration on the Carrageenan Functional Group Composition. In R. Pogaku, A. Bono, & C. Chu (Eds.), *Developments in Sustainable Chemical and Bioprocess Technology* (pp. 355–363). Boston, MA: Springer US.

Aramyan, L., Ondersteijn, C., van Kooten, O., & Lansink, A. (2006). Performance indicators in agri-food production chains. In C. J. M. Ondersteijn (Ed.), *Wageningen UR frontis series: v. 15. Quantifying the agri-food supply chain* (pp. 49–66). Dordrecht: Springer.

Aramyan, L. H., Oude Lansink, A. G., van der Vorst, Jack G.A.J., & van Kooten, O. (2007). Performance measurement in agri-food supply chains: A case study. *Supply Chain Management: An International Journal, 12*(4), 304–315. doi:10.1108/13598540710759826

Armisen, R., & Galatas, F. (2009). Agar. In G. O. Phillips & P. A. Williams (Eds.), *Woodhead Publishing Series in Food Science, Technology and Nutrition. Handbook of Hydrocolloids* (2nd ed., pp. 82–107). Cambridge: Woodhead Pub.

Baga, L. (2013). *Co-Operative Entrepreneurs and Agribusiness Development. A study towards the development of agribusiness co-operatives in Indonesia* (Dissertation). Philipps-Universität Marburg, Germany. Retrieved from http://archiv.ub.uni-marburg.de/diss/z2013/0479/pdf/dlmb.pdf

Barbier, E. B. (1987). The Concept of Sustainable Economic Development. *Environmental Conservation, 14*(02), 101. doi:10.1017/S0376892900011449

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. *Supply Chain Management: An International Journal, 9*(1), 30–42. doi:10.1108/13598540410517566

Becker, K. J., & Rotmann, K. W. G. (1990). A marketing approach to agar. *Journal of Applied Phycology, 2*(2), 105–110. doi:10.1007/BF00023371

Behzadian, M., Kazemzadeh, R. B., Albadvi, A., & Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. *European Journal of Operational Research, 200*(1), 198–215. doi:10.1016/j.ejor.2009.01.021

Bekefi, T., Jenkins, B., & Kytie, B. (2006). *Social Risk as Strategic Risk*. Cambridge, MA: John F. Kennedy School of Government, Harvard University. Retrieved from http://www.ksg.harvard.edu/m-rcbg/CSRI/research/publications/workingpaper_30_bekefietal.pdf

Belton, V., & Stewart, T. J. (2002). *Multiple criteria decision analysis: An integrated approach*. Boston: Kluwer Academic Publishers.

Bertsch, V. (2008). *Uncertainty handling in multi attribute decision support for industrial risk management* (Dissertation). Universität Karlsruhe (TH), Germany.

Bixler, H. J., & Porse, H. (2011). A decade of change in the seaweed hydrocolloids industry. *Journal of Applied Phycology, 23*(3), 321–335. doi:10.1007/s10811-010-9529-3

Blos, M. F., Quaddus, M., Wee, H. M., & Watanabe, K. (2009). Supply chain risk management (SCRM): A case study on the automotive and electronic industries in Brazil. *Supply Chain Management: An International Journal, 14*(4), 247–252. doi:10.1108/13598540910970072

Borcherding, K., Eppel, T., & Winterfeldt, D. von. (1991). Comparison of weighting judgments in multiattribute utility measurement. *Management Science, 37*(12), 1603–1619. doi:10.1287/mnsc.37.12.1603

Brans, J. P., & Vincke, P. (1985). Note—A Preference Ranking Organisation Method. *Management Science, 31*(6), 647–656. doi:10.1287/mnsc.31.6.647

Brans, J. P., Vincke, P., & Mareschal, B. (1986). How to select and how to rank projects: The Promethee method. *European Journal of Operational Research, 24*(2), 228–238. doi:10.1016/0377-2217(86)90044-5

Brans, J.-P., & Mareschal, B. (1994). The PROMCALC & GAIA decision support system for multicriteria decision aid. *Decision Support Systems, 12*(4-5), 297–310. doi:10.1016/0167-9236(94)90048-5

Brans, J.-P., & Mareschal, B. (2005). Promethee Methods. In J. Figueira, S. Greco, & M. Ehrogott (Eds.), *International series in operations research & management science. Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 163–186). New York: Springer-Verlag.

Chapman, P., Christopher, M., Jüttner, U., Peck, H., & Wilding, R. (2002). Identfying and managing supply chain vulnerability. *Logistics & Transport Focus, 4*(4), 59–70. Retrieved from http://eureka.bodleian.ox.ac.uk/id/eprint/1962

Charnes, A., & Cooper, W. W. (1957). Management models and industrial applications of linear programming. *Management Science, 4*(1), 38–91. doi:10.1287/mnsc.4.1.38

Chattopadhyay, S., Mitra, M., & Sengupta, S. (2011). *Electric Power Quality*. Dordrecht: Springer Netherlands.

Chavez, P., & Seow, C. (2012). Managing food quality risk in global supply chain:: A risk Management Framework. *International Journal of Engineering Business Management, 4*(1), 1–8. Retrieved from http://cdn.intechopen.com/pdfs-wm/36338.pdf

Chicken, J. C., & Posner, T. (1998). *The philosophy of risk*. London: Thomas Telford.

Chopra, S., & Meindl, P. (2013). *Supply chain management: Strategy, planning, and operation* (5th ed.). Boston: Pearson.

Choudhary, V., van Engelen, A., Sebadduka, S., & Valdivia, P. (2011). *Uganda dairy supply chain risk assessment* (Vol. 1). Washington DC. Retrieved from http://documents.worldbank.org/curated/en/2011/02/17694201/uganda-dairy-supply-chain-risk-assessment

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management, 34*(5), 388–396. doi:10.1108/09600030410545436

Christopher, M., & Peck, H. (2004). Building the Resilient Supply Chain. *The International Journal of Logistics Management, 15*(2), 1–14. doi:10.1108/09574090410700275

Chung, I. K., Oak, J. H., Lee, J. A., Shin, J. A., Kim, J. G., & Park, K.-S. (2013). Installing kelp forests/seaweed beds for mitigation and adaptation against global warming: Korean Project Overview. *ICES Journal of Marine Science, 70*(5), 1038–1044. doi:10.1093/icesjms/fss206

Chung, I. K., Beardall, J., Mehta, S., Sahoo, D., & Stojkovic, S. (2011). Using marine macroalgae for carbon sequestration: A critical appraisal. *Journal of Applied Phycology, 23*(5), 877–886. doi:10.1007/s10811-010-9604-9

Cicin-Sain, B. (1993). Sustainable development and integrated coastal management. *Ocean & Coastal Management, 21*(1-3), 11–43. doi:10.1016/0964-5691(93)90019-U

Conservation International. (2008). *Economic values of coral reefs, mangroves, and seagrasses: A global compilation*. Retrieved from http://www.icriforum.org/sites/default/files/Economic_values_global%20compilation.pdf

Coppejans, E., & van Reine, W. (1989). Seaweeds of the Snellius-II expedition Chlorophyta: Caulerpales (Except Caulerpa and Halimeda). *Blumea, 34,* 119–142. Retrieved from http://www.repository.naturalis.nl/document/566296

Coppejans, E., & van Reine, W. (1992). The Oceanographic Snellius-II expedition. Botanical results. List of Stations and Collected Plants. *Bulletin Séanc. Acad. R. Sci. Outre-Mer - Meded. Zitt. K. Acad. Kolon. Wet, 37,* 153–194.

Corominas, A. (2013). Supply chains: What they are and the new problems they raise. *International Journal of Production Research, 51*(23-24), 6828–6835. doi:10.1080/00207543.2013.852700

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., & Handfield, R. B. (2007). The severity of supply chain disruptions: Design characeristics and mitigation cpabilities. *Decision Sciences, 38*(1). Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1540-5915.2007.00151.x/epdf

CyberColloids Ltd. (2012). *Carrageenan Industry Report 2012*. County Cook, Ireland. Retrieved from http://www.cybercolloids.net/downloads

Demirel, S. (2012). *Strategic Supply Chain Management with Multiple Products under Supply and Capacity Uncertainty* (Dissertation). The University of Michigan, The USA. Retrieved from http://deepblue.lib.umich.edu/bitstream/handle/2027.42/93917/sdemirel_1.pdf?sequence=1

Diakoulaki, D., & Karangelis, F. (2007). Multi-criteria decision analysis and cost–benefit analysis of alternative scenarios for the power generation sector in Greece. *Renewable and Sustainable Energy Reviews, 11*(4), 716–727. doi:10.1016/j.rser.2005.06.007

Dyer, J. S. (2005). MAUT— Multiattribute Utility Theory. In J. Figueira, S. Greco, & M. Ehrogott (Eds.), *International series in operations research & management science. Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 265–292). New York: Springer-Verlag.

Edwards, W. (1977). How to use multiattribute utility measurement for social decision making. *IEEE Transactions on Systems, Man, and Cybernetics, 7*(5), 326–340. doi:10.1109/TSMC.1977.4309720

Edwards, W., & Barron, F. (1994). SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement. *Organizational Behavior and Human Decision Processes, 60*(3), 306–325. doi:10.1006/obhd.1994.1087

Eigner-Thiel, S., Schmehl, M., Ibendorf, J., & Geldermann, J. (2013). Assessment of Different Bioenergy Concepts in Terms of Sustainable Development. In H. Ruppert, M. Kappas, & J. Ibendorf (Eds.), *Sustainable Bioenergy Production - An Integrated Approach* (pp. 339–384). Dordrecht: Springer Netherlands.

Faisal, M., Banwet, D. K., & Shankar, R. (2007). Management of risk in supply chains: SCOR approach and Analytical Network Process. *Supply Chain Forum: An International Journal, 8*(2), 66–79. Retrieved from http://www.supplychain-forum.com/documents/articles/SCFvol8_2_2007_Faisal,%20Banwet%20%26%20Shankar.pdf

Faisal, M. N. (2009). Prioritization of Risks in Supply Chains. In T. Wu & J. Blackhurst (Eds.), *Managing Supply Chain Risk and Vulnerability* (pp. 41–66). London: Springer London.

Ferrol-Schulte, D., Wolff, M., Ferse, S., & Glaser, M. (2013). Sustainable Livelihoods Approach in tropical coastal and marine social–ecological systems: A review. *Marine Policy, 42*(0), 253–258. doi:10.1016/j.marpol.2013.03.007

Figueira, J., Greco, S., & Ehrgott, M. (Eds.). (2005). *International series in operations research & management science*. *Multiple criteria decision analysis: State of the art surveys*. New York: Springer.

Fitrianto, A. R., & Hadi, S. (2012). Supply Chain Risk Management in Shrimp Industry before and during Mud Volcano Disaster: An Initial Concept. *Procedia - Social and Behavioral Sciences, 65,* 427–435. doi:10.1016/j.sbspro.2012.11.144

Food and Agricultural Organization of the United Nations. (1999). *Indicators for sustainable development of marine capture fisheries*. *FAO technical guidelines for responsible fisheries: Vol. 8*. Rome: Food and Agriculture Organization of the United Nations.

Food and Agriculture Organization of the United Nations. (1995). *Code of conduct for responsible fisheries*. Rome. Retrieved from https://www.google.de/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=code+of+conduct+for+responsible+fisheries+pdf

Franck, C. (2007). Framework for supply chain risk management. *Supply Chain Forum: An International Journal, 8*(2), 2–13. Retrieved from http://www.supplychain-forum.com/documents/articles/SCFvol8_2_2007_Carolina%20Franck.pdf

French, S. (2003). Modelling, making inferences and making decisions: The roles of sensitivity analysis. *Top, 11*(2), 229–251. doi:10.1007/BF02579043

French, S., Bedford, T., & Atherton, E. (2005). Supporting ALARP decision making by cost benefit analysis and multiattribute utility theory. *Journal of Risk Research, 8*(3), 207–223. doi:10.1080/1366987042000192408

French, S., & Geldermann, J. (2005). The varied contexts of environmental decision problems and their implications for decision support. *Environmental Science & Policy, 8*(4), 378–391. doi:10.1016/j.envsci.2005.04.008

Frey, B. B. (2006). Measuring Collaboration Among Grant Partners. *American Journal of Evaluation, 27*(3), 383–392. doi:10.1177/1098214006290356

Frosdick, S. (1997). The techniques of risk analysis are insufficient in themselves. *Disaster Prevention and Management, 6*(3), 165–177. doi:10.1108/09653569710172937

Gao, K., & McKinley, K. R. (1994). Use of macroalgae for marine biomass production and CO2 remediation: A review. *Journal of Applied Phycology, 6*(1), 45–60. doi:10.1007/BF02185904

Garcia, S., Staples, D., & Chesson, J. (2000). The FAO guidelines for the development and use of indicators for sustainable development of marine capture fisheries and an Australian example of their application. *Ocean & Coastal Management, 43*(7), 537–556. doi:10.1016/S0964-5691(00)00045-4

Geldermann, J., Bertsch, V., Treitz, M., French, S., Papamichail, K., & Hamalainen, R. (2009). Multi-criteria decision support and evaluation of strategies for nuclear remediation management☆. *Omega, 37*(1), 238–251. doi:10.1016/j.omega.2006.11.006

Geldermann, J., & Rentz, O. (2001). Integrated technique assessment with imprecise information as a support for the identification of best available techniques (BAT). *OR Spektrum, 23*(1), 137–157. doi:10.1007/PL00013341

Geldermann, J., & Rentz, O. (2005). Multi-criteria Analysis for Technique Assessment: Case Study from Industrial Coating. *Journal of Industrial Ecology, 9*(3), 127–142. doi:10.1162/1088198054821591

Geldermann, J., & Schöbel, A. (2011). On the Similarities of Some Multi-Criteria Decision Analysis Methods. *Journal of Multi-Criteria Decision Analysis, 18*(3-4), 219–230. doi:10.1002/mcda.468

Geldermann, J., Spengler, T., & Rentz, O. (2000). Fuzzy outranking for environmental assessment. Case study: Iron and steel making industry. *Fuzzy Sets and Systems, 115*(1), 45–65. doi:10.1016/S0165-0114(99)00021-4

Georgopoulou, E., Sarafidis, Y., & Diakoulaki, D. (1998). Design and implementation of a group DSS for sustaining renewable energies exploitation. *European Journal of Operational Research, 109*(2), 483–500. doi:10.1016/S0377-2217(98)00072-1

Ghadge, A., Dani, S., & Kalawsky, R. (2012). Supply chain risk management: Present and future scope. *The International Journal of Logistics Management, 23*(3), 313–339. doi:10.1108/09574091211289200

Giunipero, L. C., & Aly Eltantawy, R. (2004). Securing the upstream supply chain: a risk management approach. *International Journal of Physical Distribution & Logistics Management, 34*(9), 698–713. doi:10.1108/09600030410567478

Glicksman, M. (1987). Utilization of seaweed hydrocolloids in the food industry. In M. A. Ragan & C. J. Bird (Eds.), *Twelfth International Seaweed Symposium* (pp. 31–47). Dordrecht: Springer Netherlands.

Gray, J. S. (1997). Marine biodiversity: patterns, threats and conservation needs. *Biodiversity and Conservation, 6,* 153–175. Retrieved from http://www.avesmarinhas.com.br/20%20-%20marine%20biodiversity%20%20patterns,%20threats%20and.pdf

Greening, L. A., & Bernow, S. (2004). Design of coordinated energy and environmental policies: Use of multi-criteria decision-making. *Energy Policy, 32*(6), 721–735. doi:10.1016/j.enpol.2003.08.017

Grose, V. L. (1992). Risk management from a technological perspective. *The Geneca Papers on Risk and Insurance, 17*(64), 335–342. Retrieved from https://www.genevaassociation.org/media/227994/ga1992_gp17%2864%29_grose.pdf

Hallikas, J., Virolainen, V.-M., & Tuominen, M. (2002). Risk analysis and assessment in network environments: A dyadic case study. *International Journal of Production Economics, 78*(1), 45–55. doi:10.1016/S0925-5273(01)00098-6

Hansson, S. O. (2004). Philosophical Perspectives on Risk. *Techné: Research in Philosophy and Technology, 8*(1), 10–35. doi:10.5840/techne2004818

Harland, C., Brenchley, R., & Walker, H. (2003). Risk in supply networks. *Supply Chain Management: Selected Papers from the European Operat ions Management Association (EurOMA) 8th International Annual Conference, 9*(2), 51–62. doi:10.1016/S1478-4092(03)00004-9

Heckmann, I., Comes, T., & Nickel, S. (2015). A critical review on supply chain risk – Definition, measure and modeling. *Omega, 52,* 119–132. doi:10.1016/j.omega.2014.10.004

Hendricks, K. B., & Singhal, V. R. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of Operations Management, 21*(5), 501–522. doi:10.1016/j.jom.2003.02.003

Hendricks, K. B., & Singhal, V. R. (2005a). Association Between Supply Chain Glitches and Operating Performance. *Management Science, 51*(5), 695–711. doi:10.1287/mnsc.1040.0353

Hendricks, K. B., & Singhal, V. R. (2005b). An Empirical Analysis of the Effect of Supply Chain Disruptions on Long-Run Stock Price Performance and Equity Risk of the Firm. *Production and Operations Management, 14*(1), 35–52. doi:10.1111/j.1937-5956.2005.tb00008.x

Hopp, W. J., Iravani, S. M. R., & Liu, Z. (2012). Mitigating the impact of disruptions in supply chains. In H. Gurnani, A. Mehrotra, & S. Ray (Eds.), *Supply Chain Disruptions* (pp. 21–49). London: Springer London.

Hurtado, A. Q., & Cheney, D. P. (2003). Propagule Production of Eucheuma denticulatum (Burman) Collins et Harvey by Tissue Culture. *Botanica Marina, 46*(4). doi:10.1515/BOT.2003.031

Hwang, C. L., & Yoon, K. (1981). *Multiple attribute decision making: Methods and applications : a state-of-the-art survey*. *Lecture notes in economics and mathematical systems: Vol. 186*. Berlin, New York: Springer-Verlag.

Imeson, A. P. (2009). Carrageenan and furcellaran. In G. O. Phillips & P. A. Williams (Eds.), *Woodhead Publishing Series in Food Science, Technology and Nutrition. Handbook of Hydrocolloids* (2nd ed., pp. 164–185). Cambridge: Woodhead Pub.

Jüttner, U. (2005). Supply chain risk management. *The International Journal of Logistics Management, 16*(1), 120–141. doi:10.1108/09574090510617385

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: Outlining an agenda for future research. *International Journal of Logistics Research and Applications, 6*(4), 197–210. doi:10.1080/13675560310001627016

Keeney, R. L. (1992). *Value-focused thinking: A path to creative decisionmaking*. Cambridge, Mass.: Harvard University Press.

Keeney, R. L., & Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*. *Wiley series in probability and mathematical statistics*. New York: Wiley.

Kersten, W., Böger, M., Hohrath, P., & Späth, H. (2006). Supply Chain Risk Management:: Development of a theoretical and empirical framework. In W. Kersten & T. Blecker (Eds.), *Operations and technology management: v. 1. Managing risks in supply chains. How to build reliable collaboration in logistics* (pp. 3–18). Berlin: Erich Schmidt.

Khan, O., & Burnes, B. (2007). Risk and supply chain management: Creating a research agenda. *The International Journal of Logistics Management, 18*(2), 197–216. doi:10.1108/09574090710816931

Khan, O., Christopher, M., & Burnes, B. (2008). The impact of product design on supply chain risk: A case study. *International Journal of Physical Distribution & Logistics Management, 38*(5), 412–432. doi:10.1108/09600030810882834

Khan, O., Christopher, M., & Burnes, B. (2009). The Role of Product Design in Global Supply Chain Risk Management. In F. S. Hillier, G. A. Zsidisin, & B. Ritchie (Eds.), *International series in operations research & management science. Supply Chain Risk* (pp. 137–153). Boston, MA: Springer US.

Kirby, R. M., Bartram, J., & Carr, R. (2003). Water in food production and processing: Quantity and quality concerns. *Food Control, 14*(5), 283–299. doi:10.1016/S0956-7135(02)00090-7

Kleindorfer, P. R., & Saad, G. H. (2005). Managing Disruption Risks in Supply Chains. *Production and Operations Management, 14*(1), 53–68. doi:10.1111/j.1937-5956.2005.tb00009.x

Korhonen, P., Moskowitz, H., & Wallenius, J. (1992). Multiple criteria decision support - A review. *European Journal of Operational Research, 63*(3), 361–375. doi:10.1016/0377-2217(92)90155-3

Kraljic, P. ((1983). Purchasing must become supply management. *Harvard Business Review, 5,* 109–117. Retrieved from https://hbr.org/1983/09/purchasing-must-become-supply-management

Kuchiki, A., & Tsuji, M. (2005). *Industrial clusters in Asia: Analyses of their competition and cooperation*. Basingstoke [England], New York: Palgrave Macmillan.

Lambert, D. M., Cooper, M. C., & Pagh, J. D. (1998). Supply Chain Management: Implementation Issues and Research Opportunities. *The International Journal of Logistics Management, 9*(2), 1–20. doi:10.1108/09574099810805807

Lavastre, O., Gunasekaran, A., & Spalanzani, A. (2012). Supply chain risk management in French companies. *Decision Support Systems, 52*(4), 828–838. doi:10.1016/j.dss.2011.11.017

Leat, P., & Revoredo-Giha, C. (2013). Risk and resilience in agri-food supply chains: The case of the ASDA PorkLink supply chain in Scotland. *Supply Chain Management: An International Journal, 18*(2), 219–231. doi:10.1108/13598541311318845

Lee, H. L. (2004). *The triple A supply chain*. Retrieved from https://www.google.de/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=the+triple+a+supply+chain+Lee

Leon, S. M. (2014). *Sustainability in supply chain management casebook: Applications in SCM*. Upper Saddle River, N.J.: Pearson.

Løken, E. (2007). Use of multicriteria decision analysis methods for energy planning problems. *Renewable and Sustainable Energy Reviews, 11*(7), 1584–1595. doi:10.1016/j.rser.2005.11.005

Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management strategies. *International Journal of Physical Distribution & Logistics Management, 38*(3), 192–223. doi:10.1108/09600030810866986

March, J. G., & Zur Shapira. (1987). Managerial perspectives on risk and risk taking. *Management Science, 33*(11), 1404–1418. Retrieved from http://www.jstor.org/stable/2631920

Mareschal, B. (2011). *What is a correct value for an indifference threshold (q)?* Retrieved from http://www.promethee-gaia.net/faq-pro/index.php?action=article&cat_id=003002&id=5

Mareschal, B. (2012a). *How to choose the right preference function?* Retrieved from http://www.promethee-gaia.net/faq-pro/?action=article&cat_id=003002&id=4&lang=

Mareschal, B. (2012b). *Should the value of the indifference (Q) and preference thresholds (P) be in the interval: min |Dc(Ai,Aj)| <= q <= p <= max |Dc(Ai,Aj)| ? where min |Dc(Ai,Aj)| or max |Dc(Ai,Aj)| is the lowest / the highest deviation value for criterion c? So, it won't make sense if we set Q or P out of the interval. Is that right?* Retrieved from http://www.promethee-gaia.net/faq-pro/index.php?action=article&cat_id=003002&id=36

Marine Stewardship Council. (2014). *Industry update: MSC to develop sustainable seaweed standard*. Retrieved from http://www.msc.org/newsroom/news/industry-update-msc-to-develop-sustainable-seaweed-standard

Mason-Jones, R., & Towill, D. R. (1997). Information enrichment: Designing the supply chain for competitive advantage. *Supply Chain Management: An International Journal, 2*(4), 137–148. doi:10.1108/13598549710191304

Matthews, B. (1996). *A critical review of proposals, their scientific and political context, and possible impacts*. Retrieved from http://www.chooseclimate.org/cleng/part1b.html

McHugh, D. J. (2003). *A guide to the seaweed industry*. *FAO fisheries technical paper: Vol. 441*. Rome: Food and Agriculture Organization of the United Nations.

McLachlan, J. (1985). Macroalgae (seaweeds): industrial resources and their utilization. In D. Pasternak & A. San Pietro (Eds.), *Biosalinity in Action: Bioproduction with Saline Water* (pp. 137–157). Dordrecht: Springer Netherlands.

Mentzer, J. T., Stank, T. P., & Esper, T. L. (2008). SUPPLY CHAIN MANAGEMENT AND ITS RELATIONSHIP TO LOGISTICS, MARKETING, PRODUCTION, AND OPERATIONS MANAGEMENT. *Journal of Business Logistics, 29*(1), 31–46. doi:10.1002/j.2158-1592.2008.tb00067.x

Merril, J. M. (2007). *Managing Risk in Premium Fruit and Vegetable Supply Chains* (Dissertation). Massachusetts Institute of Technology, USA. Retrieved from http://dspace.mit.edu/bitstream/handle/1721.1/40115/185056840.pdf?…

Milani, J., & Maleki, G. (2012). Hydrocolloids in Food Industry. In B. Valdez (Ed.), *Food Industrial Processes - Methods and Equipment* (pp. 17–38). InTech. Retrieved from http://cdn.intechopen.com/pdfs-wm/29151.pdf

Miller, K. D. (1992). A framework for integrated risk management in international business. *Journal of International Business Studies, 23*(2), 311–331. Retrieved from http://www.jstor.org/stable/154903

Milliken, F. J. (1987). Three types of perceived uncertainty about the environment: State, Effect, and Response Uncertainty. *Academy of Management, 12*(1), 133–143. Retrieved from http://www.jstor.org/stable/257999?seq=1#page_scan_tab_contents

Center of Data, Statistics, and Information. (2014a). *Analisis Data Pokok Kelautan dan Perikanan 2014*. Jakarta. Retrieved from http://statistik.kkp.go.id/index.php/arsip/c/89/Analisis-Data-Pokok-Kelautan-dan-Perikanan-2014/?category_id=3

Ministry of Marine Affairs and Fisheries, Republic of Indonesia. (2014b). *Marine and Fisheries in Figures 2014*. Jakarta.

Mitchell, V.-W. (1995). Organizational Risk Perception and Reduction: A Literature Review. *British Journal of Management, 6*(2), 115–133. doi:10.1111/j.1467-8551.1995.tb00089.x

Moberg, F., & Rönnbäck, P. (2003). Ecosystem services of the tropical seascape: interactions, substitutions and restoration. *Ocean & Coastal Management, 46*(1–2), 27–46. doi:10.1016/S0964-5691(02)00119-9

Möller, N. (2012). The Concepts of Risk and Safety. In S. Roeser, R. Hillerbrand, P. Sandin, & M. Peterson (Eds.), *Handbook of Risk Theory* (pp. 55–85).

Moore, P. G. (1983). *The business of risk*. Cambridge [Cambridgeshire], New York: Cambridge University Press.

Morosini, P. (2004). Industrial Clusters, Knowledge Integration and Performance. *World Development, 32*(2), 305–326. doi:10.1016/j.worlddev.2002.12.001

Muraoka, D. (2004). Seaweed resources as a source of carbon fixation. *Bulletin of Fisheries Research Agency, 1,* 59–63. Retrieved from http://www.climatebabes.com/documents/Carbon%20absorved%20by%20seaweed.pdf

Mustajoki, J., Hamalainen, R. P., & Salo, A. (2005). Decision Support by Interval SMART/SWING-Incorporating Imprecision in the SMART and SWING Methods. *Decision Sciences, 36*(2), 317–339. doi:10.1111/j.1540-5414.2005.00075.x

Narasimhan, R., & Talluri, S. (2009). Perspectives on risk management in supply chains. *Special Issue: Perspectives on Risk Management in Supply Chains, 27*(2), 114–118. doi:10.1016/j.jom.2009.02.001

Necas, J., & Bartosikova, L. (2013). Carrageenan: a review. *Veterinarni Medicina, 58*(4), 187–205. Retrieved from http://vri.cz/docs/vetmed/58-4-187.pdf

Neish, I. C. (2013). Social and economic dimensions of carrageenan seaweed farming in Indonesia. In D. Valderrama, J. Cai, N. Hishamunda, & N. B. Ridler (Eds.), *FAO fisheries and aquaculture technical paper: Vol. 580. Social and economic dimensions of carrageenan seaweed farming* (pp. 61–89). Rome: FAO.

Nishat Faisal, M., Banwet, D. K., & Shankar, R. (2006). Supply chain risk mitigation: Modeling the enablers. *Business Process Management Journal, 12*(4), 535–552. doi:10.1108/14637150610678113

Normah, O., & Nazarifah, I. (2003). Production of semi-refined carrageenan from locally available red seaweed, Eucheuma cottonii on a laboratory scale. *Journal of Tropical Agriculture and Food Science, 31*(12). Retrieved from http://rac1.mardi.gov.my/jtafs/31-2/Semi-refined%20carrageenan.pdf

Norrman, A., & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution & Logistics Management, 34*(5), 434–456. doi:10.1108/09600030410545463

Nurdjana, M. L., Ismanadji, I., Surono, A., & Danakusumah, E. (2009). *Profil Rumput Laut Indonesia*. Jakarta: Directorate General of Aquaculture, Directorate of Production.

Oberschmidt, J., Geldermann, J., Ludwig, J., & Schmehl, M. (2010). Modified PROMETHEE approach for assessing energy technologies. *International Journal of Energy Sector Management, 4*(2), 183–212. doi:10.1108/17506221011058696

Orr, J. C., & Sarmiento, J. L. (1992). Potential of marine macroalgae as a sink for CO2: Constraints from a 3-D general circulation model of the global ocean. *Water, Air, & Soil Pollution, 64*(1-2), 405–421. doi:10.1007/BF00477113

Panlibuton, H., Porse, H., & Nadela, E. (2007). *Seaweed/Carrageenan value Chain Assessment: Final Report.* Arlington, VA, USA.

Parizat, R., van Hilten, J., Wunderlich, C., & Nsibirwa, R. (2011). *Ugandan Coffee Supply Chain Risk Assessment*. Washington DC: World Bank. Retrieved from http://documents.worldbank.org/curated/en/2011/06/17694191/ugandan-coffee-supply-chain-risk-assessment

Peck, H. (2005). Drivers of supply chain vulnerability: An integrated framework. *International Journal of Physical Distribution & Logistics Management, 35*(4), 210–232. doi:10.1108/09600030510599904

Peterson Drake, P., & Fabozzi, F. J. (2010). *The basics of finance: An introduction to financial markets, business finance, and portfolio management*. *The Frank J. Fabozzi series*. Hoboken, NJ: Wiley.

Pfohl, H.-C., Köhler, H., & Thomas, D. (2010). State of the art in supply chain risk management research: empirical and conceptual findings and a roadmap for the implementation in practice. *Logistics Research, 2*(1), 33–44. doi:10.1007/s12159-010-0023-8

Phillips, G. O., & Williams, P. A. (Eds.). (2009). *Woodhead Publishing Series in Food Science, Technology and Nutrition*. *Handbook of Hydrocolloids* (2nd ed.). Cambridge: Woodhead Pub.

Pollnac, R. B., Pomeroy, R. S., & Harkes, I. H. (2001). Fishery policy and job satisfaction in three southeast Asian fisheries. *Ocean & Coastal Management, 44*(7-8), 531–544. doi:10.1016/S0964-5691(01)00064-3

Porter, M. E. (1998). Clusters and the New Economics of Competition. *Harvard Business Review, 76*(6), 77–90. Retrieved from https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition

Potts, T. (2006). A framework for the analysis of sustainability indicator systems in fisheries. *Ocean & Coastal Management, 49*(5-6), 259–280. doi:10.1016/j.ocecoaman.2006.03.008

Ragatz, G. L., Handfield, R. B., & Petersen, K. J. (2002). Benefits associated with supplier integration into new product development under conditions of technology uncertainty. *Journal of Business Research, 55*(5), 389–400. doi:10.1016/S0148-2963(00)00158-2

Raj Sinha, P., Whitman, L. E., & Malzahn, D. (2004). Methodology to mitigate supplier risk in an aerospace supply chain. *Supply Chain Management: An International Journal), 9*(2), 154–168. doi:10.1108/13598540410527051

Renn, D. W. (1986). Uses of marine algae in biotechnology and industry. In Indonesian National Research Council & National Research Council (U.S.). Office of International Affairs (Eds.), *Workshop on marine algae biotechnology. Summary report* (pp. 16–30). Washington DC: National Academy Press.

Renn, O. (1998). Three decades of risk research: accomplishments and new challenges. *Journal of Risk Research, 1*(1), 49–71. doi:10.1080/136698798377321

Rice, J. B., & Caniato, F. (2003). Building a secure and resilient supply network. *Supply Chain Management Review*, (September/October), 22–30. Retrieved from www.scmr.com

Ritchie, B., & Brindley, C. (2007). Supply chain risk management and performance. *International Journal of Operations & Production Management), 27*(3), 303–322. doi:10.1108/01443570710725563

Ritschard, R. L. (1992). Marine algae as a co2 sink. *Water, Air, & Soil Pollution, 64*(1-2), 289–303. doi:10.1007/BF00477107

Rogers, P. P., Jalal, K. F., & Boyd, J. A. (2008). *An introduction to sustainable development*. London, Sterling, VA: Earthscan.

Roy, B. (1990). Decision-aid and decision-making. *European Journal of Operational Research, 45*(2-3), 324–331. doi:10.1016/0377-2217(90)90196-I

Royal Society Study Group on Risk Assessment. (1992). *Risk: analysis, perception, measurement*. London: Royal Society.

Ruther, B. (Ed.) 2009. *Risk management of unintended GMO contamination in the supply chain of maize and processed maize products*. Retrieved from http://ageconsearch.umn.edu/bitstream/58128/2/Ruther.pdf

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting, resource allocation*. New York, London: McGraw-Hill International Book Co.

Saaty, T. L., & Vargas, L. G. (2006). *Decision making with the analytic network process: Economic, political, social and technological applications with benefits, opportunities, costs and risks*. *International series in operations research & management science: Vol. 95*. New York: Springer.

Sadgrove, K. (2005). *The complete guide to business risk management*. Aldershot, Hants, England, Burlington, VT: Gower.

Sala, E., & Knowlton, N. (2006). Global Marine Biodiversity Trends. *Annual Review of Environment and Resources, 31*(1), 93–122. doi:10.1146/annurev.energy.31.020105.100235

Sarpong, K. O., Alexander, O. F., & Anin, E. K. (2013). An assessment of supply chain risks in the cocoa industry in the Ashanti Regiion, Ghana. *International Journal of Humanities and Social Science, 3*(19). Retrieved from http://www.ijhssnet.com/journals/Vol_3_No_19_November_2013/24.pdf

Schoemaker, P. J. H., & Waid, C. C. (1982). An experimental comparison of different approaches to determining weights in additive utility models. *Management Science, 28*(2), 182–196. doi:10.1287/mnsc.28.2.182

Schütz, V., Lehnert, S., & Nüssel, M. (2014). Quality management and quality assurance in supply chains to food retail. In B. Petersen, M. Nüssel, & M. Hamer (Eds.), *Quality and risk management in agri-food chains* (pp. 29–38). Wageningen, The Netherlands: Wageningen Academic Publishers.

Sethi, G., Costello, C., Fisher, A., Hanemann, M., & Karp, L. (2005). Fishery management under multiple uncertainty. *Journal of Environmental Economics and Management, 50*(2), 300–318. doi:10.1016/j.jeem.2004.11.005

Shen, X., Liu, Q., & Zhao, D. (2013). Evaluation on The Risk of Chinese Agri-Food Supply Chain. *Journal of Convergence Information Technology, 8*(9), 802–809. doi:10.4156/jcit.vol8.issue9.99

Sievanen, L., Crawford, B., Pollnac, R., & Lowe, C. (2005). Weeding through assumptions of livelihood approaches in ICM: Seaweed farming in the Philippines and Indonesia. *Ocean & Coastal Management, 48*(3-6), 297–313. doi:10.1016/j.ocecoaman.2005.04.015

Siskos, Y., Grigoroudis, E., & Matsatsinis, N. F. (2005). UTA Methods. In J. Figueira, S. Greco, & M. Ehrogott (Eds.), *International series in operations research & management science. Multiple Criteria Decision Analysis: State of the Art Surveys* (pp. 297–334). New York: Springer-Verlag.

Snider, H. (1991). Risk management: A retrospective view. *Risk Management, April,* 47–54.

Sodhi, M. S., & Tang, C. S. (2012a). *Managing Supply Chain Risk* (Vol. 172). Boston, MA: Springer US.

Sodhi, M. S., & Tang, C. S. (2012b). *Managing supply chain risk*. *International series in operations research & management science: v.172*. New York: Springer.

Soegiarto, A., & Sulustijo. (1990). Utilization and farming of seaweeds. In I.J. Dogma Jr., G.C. Trono Jr., & R.A. Tabbada (Eds.), *Culture and use of algae in Southeast Asia. Proceedings of the Symposiumon Culture and Utilization of Algae in Southeast Asia* . Philippines.

Stecke, K. E., & Kumar, S. (2009). Sources of Supply Chain Disruptions, Factors That Breed Vulnerability, and Mitigating Strategies. *Journal of Marketing Channels, 16*(3), 193–226. doi:10.1080/10466690902932551

Stewart, T. J. (1992). A critical survey on the status of multiple criteria decision making theory and practice. *Omega, 20*(5-6), 569–586. doi:10.1016/0305-0483(92)90003-P

Stock, J. R., Boyer, S. L., & Harmon, T. (2010). Research opportunities in supply chain management. *Journal of the Academy of Marketing Science, 38*(1), 32–41. doi:10.1007/s11747-009-0136-2

Svensson, G. (2000). A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution & Logistics Management, 30*(9), 731–750. doi:10.1108/09600030010351444

Talluri, S. S., Kull, T. J., Yildiz, H., & Yoon, J. (2013). Assessing the Efficiency of Risk Mitigation Strategies in Supply Chains. *Journal of Business Logistics, 34*(4), 253–269. doi:10.1111/jbl.12025

Tang, C. (2006). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics, 9*(1), 33–45. doi:10.1080/13675560500405584

Tang, C., & Tomlin, B. (2008a). The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics, 116*(1), 12–27. doi:10.1016/j.ijpe.2008.07.008

Tang, C., & Tomlin, B. (2009b). How Much Flexibility Does It Take to Mitigate Supply Chain Risks? In F. S. Hillier, G. A. Zsidisin, & B. Ritchie (Eds.), *International series in operations research & management science. Supply Chain Risk* (pp. 155–174). Boston, MA: Springer US.

Tang, C. S. (2006). Perspectives in supply chain risk management. *International Journal of Production Economics, 103*(2), 451–488. doi:10.1016/j.ijpe.2005.12.006

Tang, O., & Musa, S. N. (2011). Identifying risk issues and research advancements in supply chain risk management. *International Journal of Production Economics, 133*(1), 25–34. doi:10.1016/j.ijpe.2010.06.013

Thun, J.-H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *Innsbruck 2008, 131*(1), 242–249. doi:10.1016/j.ijpe.2009.10.010

Tomlin, B. (2006). On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks. *Management Science, 52*(5), 639–657. doi:10.1287/mnsc.1060.0515

Trkman, P., & McCormack, K. (2009). Supply chain risk in turbulent environments—A conceptual model for managing supply chain network risk. *International Journal of Production Economics, 119*(2), 247–258. doi:10.1016/j.ijpe.2009.03.002

Tummala, R., & Schoenherr, T. (2011). Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Management: An International Journal, 16*(6), 474–483. doi:10.1108/13598541111171165

The United Nations Commodity Trade Statistics Database (UN Comtrade) (2009 -2013). Comtrade data on seaweed, tuna, and shrimp: United Nations Publications Board. Retrieved from http://comtrade.un.org/db/help/ureadMeFirst.aspx?returnPath=%2fdb%2fdqBasicQueryResults.aspx%3fcc%3d130239%26px%3dH0%26rg%3d1%26r%3d360

the United Nations Conference on Environment and Development (UNCED). (1993). *Agenda 21: Programme of action for sustainable development. Rio declaration on environment and development [u.a.]*. New York: United Nations Department of Public Information.

United Nations Convention on the Law of the Sea, United Nations Convention on the Law of the Sea (UNCLOS) 10 December/1982.

United Nations Environment Programme. (2006). *Marine and coastal ecosystems and human well-being: a synthesis report based on the findings of the millenium ecosystem assessment - Google Search*. Retrieved from http://www.unep.org/pdf/Completev6_LR.pdf

Vanany, I., Zailani, S., & Pujawan, N. (2009). Supply Chain Risk Management. *International Journal of Information Systems and Supply Chain Management, 2*(1), 16–33. doi:10.4018/jisscm.2009010102

Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several deimensions of risk. *Journal of Business Logistics, 29*(1), 307–325. Retrieved from http://enterrasolutions.com/media/docs/2012/01/Wagner_Bode_2008_An_Empirical_Examination_of_Supply_Chain_Performance_Along_Several_Dimensions_of_Risk.pdf

Wang, J.-J., Jing, Y.-Y., Zhang, C.-F., & Zhao, J.-H. (2009). Review on multi-criteria decision analysis aid in sustainable energy decision-making. *Renewable and Sustainable Energy Reviews, 13*(9), 2263–2278. doi:10.1016/j.rser.2009.06.021

Wang, X. (2014). An Integrated Fuzzy Approach for the Evaluation of Supply Chain Risk Mitigation Strategies. *Open Journal of Social Sciences, 02*(09), 161–166. doi:10.4236/jss.2014.29028

Wang, Y., Gilland, W., & Tomlin, B. (2010). Mitigating Supply Risk: Dual Sourcing or Process Improvement? *Manufacturing & Service Operations Management, 12*(3), 489–510. doi:10.1287/msom.1090.0279

Waters, C. D. J. (2007). *Supply chain risk management: Vulnerability and resilience in logistics*. London, Philadelphia: Kogan Page.

Weber, M., & Borcherding, K. (1993). Behavioral influences on weight judgments in multiattribute decision making. *European Journal of Operational Research, 67*(1), 1–12. doi:10.1016/0377-2217(93)90318-H

White, D. (1995). Application of systems thinking to risk management. *Management Decision, 33*(10), 35–45. doi:10.1108/EUM0000000003918

Wilding, R., Colicchia, C., & Strozzi, F. (2012). Supply chain risk management: A new methodology for a systematic literature review. *Supply Chain Management: An International Journal, 17*(4), 403–418. doi:10.1108/13598541211246558

Winterfeldt, D. von, & Edwards, W. (1986). *Decision analysis and behavioral research*. Cambridge [Cambridgeshire], New York: Cambridge University Press.

World Bank. (2013). *Ghana - Cocoa supply chain risk assessment* (Vol. 1). Washington DC: World Bank. Retrieved from http://documents.worldbank.org/curated/en/2013/01/17694705/ghana-cocoa-supply-chain-risk-assessment

World Commission on Environment and Development. (1987). *Our common facts*. Oxford: Oxford University Press.

Yeboah, N. E., Feng, Y., Daniel, O.-S., & Joseph, N. B. (2014). Agricultural Supply Chain Risk Identification- A Case Finding from Ghana. *Journal of Management and Strategy, 5*(2). doi:10.5430/jms.v5n2p31

Zaneveld, J. S. (1959). The utilization of marine algae in Tropical South and East Asia. *Economic Botany, 13*(2), 89–131. Retrieved from http://download-v2.springer.com/static/pdf/374/art%253A10.1007%252FBF02859244.pdf?token2=exp=1428326584~acl=%2Fstatic%2Fpdf%2F374%2Fart%25253A10.1007%25252FBF02859244.pdf*~hmac=696d5abf892cf8321f83d50f8e206685775159ebea2f4a98d55673570e2585cf

Zhou, P., Ang, B., & Poh, K. (2006). Decision analysis in energy and environmental modeling: An update. *Energy, 31*(14), 2604–2622. doi:10.1016/j.energy.2005.10.023

Zsidisin, G. A., Ellram, L. M., Carter, J. R., & Cavinato, J. L. (2004). An analysis of supply risk assessment techniques. *International Journal of Physical Distribution & Logistics Management, 34*(5), 397–413. doi:10.1108/09600030410545445

Zsidisin, G. A., Panelli, A., & Upton, R. (2000). Purchasing organization involvement in risk assessments, contingency plans, and risk management: An exploratory study. *Supply Chain Management: An International Journal, 5*(4), 187–198. doi:10.1108/13598540010347307

Zsidisin, G. A., & Ritchie, B. (2009). Supply Chain Risk Management – Developments, Issues and Challenges. In F. S. Hillier, G. A. Zsidisin, & B. Ritchie (Eds.), *International series in operations research & management science. Supply Chain Risk* (pp. 1–12). Boston, MA: Springer US.