Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Engineering
Dept. of Industrial Economics and Technology Management

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Operationalisation of sustainability of the Norwegian macroalgae aquaculture industry

Modification of the Wheel of Sustainability for salmon aquaculture to be specifically applicable to the Norwegian macroalgae aquaculture industry

Master's thesis in Industrial Ecology
Supervisor: John Eilif Hermansen
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Abstract

Industrial aquaculture with macroalgae is an emerging industry in the Western world and regarded as an important contribution to increased and sustainable ocean-based biomass production. However, like many other industries, this industry may be associated with various negative aspects with regards to sustainability. Today, there exists no model of sustainability of this industry providing an overview of such important sustainability aspects and potential interconnections and interactions between these. Such a model could be an important tool for understanding, assessment and support of decision-making, in the endeavour to ensure sustainable development of this industry.

This study aimed to identify important sustainability aspects of the Norwegian macroalgae aquaculture industry, and through this, modify *the Wheel of Sustainability (WOS)*, which is a model of sustainability of the salmon aquaculture industry providing a holistic and complexity-based overview of important sustainability aspects of this industry, to make this model be specifically applicable to the Norwegian macroalgae aquaculture industry. The main methods for data collection about important sustainability aspects of the macroalgae aquaculture industry included 15 qualitative semi-structured interviews with relevant actors from science, public administration and the industry, and a systematic literature review. All collected data were analysed and coded according to the original WOS, and used to modify this model to make it be specifically applicable to the Norwegian macroalgae aquaculture industry.

The new, modified version of the original WOS that resulted from this study is named *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)*. The results of the study show that all the overarching sustainability aspects from the original WOS, except from one, were found to be relevant also for sustainability of the Norwegian macroalgae aquaculture industry, and thus, they were included in the new WOS-MA. This shows that there are many similarities between these two related industries with regards to sustainability. However, some parts of the model, primarily the parts concerning environmental sustainability, had nevertheless to be modified to make the model be specifically applicable to the macroalgae aquaculture industry. The main reason for this is that macroalgae and salmon are fundamentally different types of organisms which affect their surrounding environment in several fundamentally different ways. Most importantly, this involves that macroalgae aquaculture, as opposed to salmon aquaculture, was found to be able to generate several positive effects on the surrounding environment in addition to potential negative effects. This constitutes a significant difference between these two related industries with regards to sustainability. The results also show that there seems to be a major focus on environmental sustainability aspects among actors within and connected to the Norwegian macroalgae aquaculture industry, while there is a less focus on some other important sustainability aspects, particularly aspects related to the role of companies of the industry as social players in relation to the communities in which they operate. The new WOS-MA, providing a holistic and complexity-based overview of identified important sustainability aspects of the Norwegian macroalgae aquaculture industry, may potentially contribute to a more holistic understanding of sustainability of this industry, and function as a tool for support of strategic decision-making in the endeavour to ensure sustainable development of the industry. However, as the knowledge about many sustainability aspects of the industry currently is relatively limited, and as there are several other aspects that make the results and implications of this study uncertain, there is a great need for more research and work to increase the understanding of sustainability of this industry and to ensure the validity of the WOS-MA.

Preface

This thesis presents my master's study which has been conducted as a part of my master's degree in Industrial Ecology at the Department of Industrial Economics and Technology Management at the Norwegian University of Science and Technology (NTNU).

The study is a continuation of a previous project work, which aimed, among other things, to provide an overview of the Norwegian macroalgae aquaculture industry and the regulative framework currently existing for this industry. This project work has with this constituted a valuable background study for this study.

The process of conducting this study has been very interesting and educational, and also very demanding. Sustainability is a comprehensive and complex field of study, and it is impossible, at least within the scope of a master's study, to immerse oneself in all important and interesting aspects of it. Although I have tried to keep a holistic perspective consistent with the purpose of the study, it has therefore been necessary to make some limitations with regards to its scope and focus.

There are many people I would like to thank in connection with the conduction of this study. As the study largely is based on the work of the creators of the Wheel of Sustainability (WOS) for the salmon aquaculture industry, I have been in regular contact with one of these creators; Vilde Steiro Amundsen, during the whole research process.
I would like to extend my greatest gratitude to Vilde for spending time providing me with information about the WOS, for regular validation of how this model has been used and presented in this study and thesis, and for essential supervision and support in general. Further, I would like to thank all the interviewees who participated in the study for spending time providing me with valuable information about the comprehensive and complex field of sustainability of the macroalgae aquaculture industry, which also has been essential for me to be able to conduct the study. I would also like to thank my main supervisor John Eilif Hermansen at NTNU and co-supervisor Céline Rebours at Møreforskning Ålesund for valuable supervision and help during the research process. Lastly, a special thanks goes to my family and good friends, for boundless support. Without you, there would have been neither a master's study nor a master's degree.

Mari Skoglund Godal

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Acronyms

ASC	Aquaculture Stewardship Council
CCS	Carbon Capture and Storage
CO_2	Carbon Dioxide
CSR	Corporate Social Responsibility
DOM	Dissolved Organic Matter
EBIT	Earnings Before Interests and Taxes
GHGs	Greenhouse Gases
HACCP	Hazard Analysis and Critical Control Point
ILO	International Labour Organisation
IMTA	Integrated Multi-Trophic Aquaculture
INNS	Invasive Non-Native Species
KLD	Norwegian Ministry of Climate and Environment
KMD	Norwegian Ministry of Local Government and Modernisation
MDGs	Millennium Development Goals
MSC	Marine Stewardship Council
NNS	Non-Native Species
NSD	Norwegian Centre for Research Data
PB	Planetary Boundaries
POM	Particulate Organic Matter
R&D	Research and Development
ROI	Return On Investment
SDGs	Sustainable Development Goals
UN	United Nations
WCED	World Commission on Environment and Development
WOS	Wheel of Sustainability
WOS-MA	Wheel of Sustainability for macroalgae aquaculture
WOS-SA	Wheel of Sustainability for salmon aquaculture

1 Introduction

Industrial aquaculture with macroalgae is an emerging industry in the Western world and regarded as an important contribution to increased and sustainable ocean-based biomass production. However, like many other industries, this industry may be associated with various negative aspects with regards to sustainability, and rapid development and expansion of the industry may have unforeseen negative consequences (Barbier et al., 2019; Cottier-Cook et al., 2016). Today, there exists no model of sustainability of this industry providing an overview of such important sustainability aspects and potential interconnections and interactions between these. Such a model could be an important tool for understanding, assessment and support of decision-making, in the endeavour to ensure sustainable development of this industry.

This study aims to identify important sustainability aspects of the Norwegian macroalgae aquaculture industry, and through this, modify *the Wheel of Sustainability (WOS)*, which is a model of sustainability of the salmon aquaculture industry providing a holistic and complexity-based overview of important sustainability aspects of this industry, to make this model be specifically applicable to the Norwegian macroalgae aquaculture industry. The following two subchapters elaborates on the background (subchapter 1.1) and the purpose and limitations (subchapter 1.2) of this study. Subchapter 1.3 provides an overview of the structure of this thesis presenting the study.

1.1 Background of the study

The global demand for food resources is rapidly increasing. To provide enough food to an expected global population of almost 10 billion people in 2050, the global food production needs to be doubled compared to that of 2013 (FAO, 2017). The world's lands and oceans account for approximately half of the world's total biomass production each, however, only 2% of our calorie intake and 15% of our protein intake come from ocean-derived food products. This implies a great potential of the oceans for meeting the increasing global demand for food resources (European Commission, 2017).

Finfish aquaculture, particularly salmon aquaculture, is considered to be an important part of the solution to meet this increasing global demand for food resources. However, the salmon aquaculture industry is associated with a number of negative sustainability aspects, where some of the most well-known are environmental sustainability aspects such as escapes and genetic pollution of wild populations, lice and diseases, pollution from aquaculture facilities and unsustainable feed sources (Klinger & Naylor, 2012). Thus, to increase the sustainability of this industry, many efforts are needed to address such aspects. It is argued, however, that true sustainability should not only be interpreted as environmental sustainability, but as a more holistic concept also including social, economic and governmental aspects (Sachs, 2015). Further, as there may exist both negative trade-offs and positive synergies between such different sustainability aspects, it is important to be aware of how the aspects may be interconnected and how they may interact with and affect each other, to achieve true, holistic sustainability (Sachs, 2015). Given this need to have such a holistic perspective on sustainability, there has recently been developed a model of sustainability of the salmon aquaculture industry named *the Wheel of Sustainability (WOS)*, which provides, exactly, a holistic overview of important aspects that should be considered in the endeavour to ensure true, holistic sustainability of this industry (Osmundsen et al., 2020).

Macroalgae are a group of marine organisms belonging to the lowest trophic level in the oceans. They are capable of producing large amounts of biomass which can be used both directly as food and as ingredients in food products, but also in many other products (Holdt & Kraan, 2011; Kılınç, Cirik, Turan, Tekogul, & Koru, 2013). Industrial aquaculture with macroalgae for large-scale production of such biomass requires no arable lands, feed, fertilizers, pesticides or fresh water, and is regarded as a promising alternative to salmon and other types of finfish aquaculture as a contribution to both increased and sustainable ocean-based biomass production (Barbier et al., 2019). However, this type of aquaculture may also be associated with various negative aspects with regards to sustainability, and rapid development and expansion of this industry may have unforeseen negative consequences (Barbier et al., 2019; Cottier-Cook et al., 2016). Today, there exists no model of sustainability providing an overview of such important sustainability aspects of this industry, like it does for the salmon aquaculture industry. Such a model could be an important tool for understanding, assessment and support of decision-making, in the endeavour to ensure sustainable development of this industry.

1.2 Purpose and limitations of the study

This study aims to:

1) Identify important sustainability aspects of the macroalgae aquaculture industry.

2) Through objective 1; modify *the Wheel of Sustainability (WOS)* for the salmon aquaculture industry, to make this model be specifically applicable to the macroalgae aquaculture industry providing a holistic overview of important sustainability aspects of this industry. To ensure a clear differentiation between the two models, the original WOS is in this thesis referred to as *the Wheel of Sustainability for salmon aquaculture (WOS-SA)*, while the new, modified version of this model being specifically applicable to the macroalgae aquaculture industry that will result from this study will be named and referred to as *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)*.

   With this, this study aims to develop a tool that can be used for holistic understanding of what sustainable macroalgae aquaculture production entails, and for support of strategic decision-making in the endeavour to ensure sustainable development of this industry.

The study has further the following limitations:

1) *Limitations with regards to the industry of focus:*
   The original WOS-SA is meant to be a universal model, designed to be applicable to salmon aquaculture all over the world (Osmundsen et al., 2020). The new WOS-MA for macroalgae aquaculture that will result from this study may also have the potential to be applicable to macroalgae aquaculture globally. However, it is primarily focused on the Norwegian macroalgae aquaculture industry, being modified from the WOS-SA mainly based on data obtained from interviews with Norwegian actors within and connected to the Norwegian macroalgae aquaculture industry where the interviews focused primarily on this industry, and from literature concerning the Norwegian industry specifically (see chapter 3 for full description of the methodology).
   The WOS-MA is further meant to be applicable to the whole value chain of the Norwegian macroalgae aquaculture industry, from harvesting of wild macroalgae for use in production of seedlings to be cultivated, to the end markets. Industrial harvesting of wild macroalgae not for use in cultivation is, however, not included.

2) *Limitation (disclaimer) with regards to the objectives of the study*:
The original WOS-SA was developed to provide a holistic reference basis for an assessment of the scope of eight different sustainability standards for salmon aquaculture in their operationalisation of sustainability (Osmundsen et al., 2020). Originally, the study presented in this thesis also included an objective of conducting a similar assessment of the scope of a sustainability standard for macroalgae aquaculture; *the ASC-MSC Seaweed Standard* (ASC & MSC, 2018), according to the new WOS-MA. Therefore, the interviews that were conducted as a main part of the data collection in this study included several questions about regulation and standardisation considered important to ask to be able to conduct such an assessment. However, sustainability is a very comprehensive and complex field of study, and the identification of important sustainability aspects of the macroalgae aquaculture industry and the modification of the WOS-SA to be specifically applicable to this industry was a comprehensive and complex task requiring many elements to be investigated during the study and presented and explained in this thesis. An additional assessment of the ASC-MSC Seaweed Standard would have required many additional elements also to be investigated, presented and explained. To keep a necessary clear scope and focus of the study and this thesis, it was therefore decided to exclude the objective of conducting an assessment of the ASC-MSC Seaweed Standard from the study, and limit the objectives to the identification of important sustainability aspects of the macroalgae aquaculture industry and the modification of the WOS-SA to be specifically applicable to this industry only. Thus, several of the questions that can be found in the interview guide used for the interviews (see Appendix A) can therefore be regarded as (more or less) irrelevant. Nevertheless, the data collected from these questions contributed to give a thorough understanding of the macroalgae aquaculture industry and its associated sustainability aspects, something which has been valuable for the study (see chapter 3 for full description of the methodology).

3) *Limitation (disclaimer) with regards to the results of the study*:
It is further important to point out that the part of this thesis providing an operationalisation of what the different sustainability aspects of the WOS-MA include and mean specifically for sustainability of the macroalgae aquaculture industry and justifications of all the different parts of this model (see subchapter 4.2), has a greater focus on some sustainability aspects, particularly environmental sustainability aspects, than on others. This is because environmental sustainability aspects were the main subject of focus among most of the interviewees, and, most importantly; because environmental sustainability was found to be the domain where the salmon and the macroalgae aquaculture industry differ most significantly, and where significant modifications of the WOS-SA had to be made to make this domain be specifically applicable to the macroalgae aquaculture industry. Thus, these aspects require more thorough operationalisation and justifications. This does not mean, however, that they are assigned any greater importance, weight, or value than other sustainability aspects of the WOS-MA.

1.3 Structure of the study

This thesis presenting the study is structured in six chapters. Following this first chapter, chapter 2 presents the relevant theoretical resources and chapter 3 describes the methodology used for achieving the objectives of the study. Chapter 4 presents the results, which are further discussed in chapter 5. Chapter 6 provides concluding remarks.

2 Theoretical resources

This chapter presents the relevant theoretical resources used for achieving the objectives of the study. First, subchapter 2.1 provides information about macroalgae, macroalgae aquaculture in general, and the Norwegian macroalgae aquaculture industry specifically. Subchapter 2.2 presents the concept of sustainability, in the "form of" the concept of sustainable development (see note below), and how this concept is understood and applied in this thesis. Subchapter 2.3 briefly elaborates on how the business sector, of which the macroalgae aquaculture industry is a part, can contribute to sustainable development. Subchapter 2.4 further elaborates on how the concept of sustainability can be modelled in a representative and useful way, while subchapter 2.5 presents and describes the Wheel of Sustainability for salmon aquaculture (WOS-SA), which has been modified in this study to make this model of sustainability be specifically applicable to the macroalgae aquaculture industry. Lastly, subchapter 2.6 presents and describes the ASC-MSC Seaweed Standard, which is a theoretical resource that has constituted a part of the data basis used in the process of this modification.

It is important to point out here that the theoretical resources used to explain how the concept of sustainability is understood and applied in this thesis, are concerned with sustainability at a macro level, that is; concerning the whole, global world. In this context, the term *sustainable development* of this whole, global world is typically used. However, as the purpose of this study involves to operationalise this concept of sustainable development at a macro level down to a micro level concerning how specific companies and industries can ensure that they are sustainable and contribute to such global sustainable development, it is more relevant and expedient to use the term *sustainability*. These two terms will therefore be used interchangeably throughout this thesis, depending on the level of focus.

2.1 The macroalgae aquaculture industry

This subchapter presents information about macroalgae and their applications (subchapter 2.1.1), macroalgae aquaculture in general (subchapter 2.1.2), and the Norwegian macroalgae aquaculture industry specifically (subchapter 2.1.3). The entire subchapter is largely based on a previous project work conducted by the researcher of this master study, as a preparation for this study. This project work aimed, among other things, to provide an overview of the Norwegian macroalgae aquaculture industry, and is therefore used as such a basis for presentation of this industry in this thesis. It should be noted here that the project work is an unpublished work, however, it can be provided for reading on request to me, the researcher of this study. It is referred to in this thesis as "Godal (2019)" (see 'References').

2.1.1 Macroalgae and their applications

Macroalgae, most often called seaweeds, is a generic term for a large and diverse group of macroscopic and multicellular marine organisms living in coastal areas all around the world. Like most terrestrial plants, macroalgae are *photoautotrophic organisms*, which means that they live exclusively on inorganic compounds (autotrophic) and are able to use energy from the sunlight (photoautotrophic) to convert some of such inorganic compounds; water and CO_2, into chemical energy and organic compounds through the process of photosynthesis, for use in respiration and growth (Mouritsen, 2013; Pereira, 2016; SNL, 2020b, 2020e). As *heterotrophic organisms* on the other hand, are dependent on organic compounds produced by photoautotrophic and other types of autotrophic organisms for their respiration and growth, autotrophic production of organic compounds constitutes the nutritional basis for the whole food web within an ecosystem, and is therefore named *primary production* (SNL, 2020g). Based on the colour of their dominating photosynthetic pigments, macroalgae can be divided into three main groups; brown algae (*Phaeophyceae*) including brown annuals, brown perennials and kelps, red algae (*Rhodophyceae*), and green algae (*Chlorophyceae*) (Duinker et al., 2016).

Many macroalgae species can grow to become many metres long, and many wild populations of such macroalgae species are typically forming large underwater forests along the coastline. Such macroalgae forests play naturally an essential role for marine and coastal ecosystems; both by being structuring species modifying the environment and primary producers supporting marine food webs, and also by providing shelters and reproductive refugia to a variety of organisms from many trophic levels (Barbier et al., 2019; Rebours et al., 2014). In addition to be playing such an essential role for marine and coastal ecosystems, macroalgae contain several valuable substances such as carbohydrates, proteins, lipids, vitamins, minerals, antioxidants, and several others, making them a valuable resource for humans as well. Historically, macroalgae have primarily been utilised for use as food, primarily by humans living in coastal communities in Asia, however, a lot of other applications for use of macroalgae biomass have developed the last years, including uses as bioactive components of functional foods, animal feeds, pharmaceuticals, cosmeceuticals, fertilizers, biofuels and many more, also in markets outside Asia (Barbier et al., 2019; Kılınç et al., 2013; Skjermo et al., 2014).

2.1.2 Macroalgae aquaculture

Along with an increased popularity of utilising macroalgae as food and increased development of other applications and markets for use of macroalgae biomass, the demand for such biomass has increased rapidly. Particularly over the last fifty years, this increased demand has led to a development of macroalgae aquaculture industries capable of large-scale production of macroalgae biomass, mainly in Asian countries (Kılınç et al., 2013). Historically, the interest in macroalgae aquaculture have been rather low in the rest of the world, however, along with the development of new applications and markets for use of macroalgae biomass, the global interest in such aquaculture has been increasing the last years. Besides giving opportunities for large-scale production of biomass, macroalgae aquaculture requires no arable lands, feed, fertilizers, pesticides or fresh water, and is therefore regarded as an important contribution to both increased and sustainable ocean-based food production (Barbier et al., 2019; Skjermo et al., 2014).

2.1.3 The Norwegian macroalgae aquaculture industry

With an extensive coastline and an already well-established salmon aquaculture industry, Norway has been found to have very suitable preconditions for macroalgae aquaculture, and to be among the countries considered to have the greatest opportunities for value creation based on such aquaculture (Olafsen, Winther, Olsen, & Skjermo, 2012; Skjermo et al., 2014; Stévant, Rebours, & Chapman, 2017). This subchapter provides an overview of the current Norwegian macroalgae aquaculture industry.

Overview of the industry
Following successful trials in several other European countries, experimental cultivation of macroalgae started in Norway around 2005. After some years with research and pilot-scale production, the first permits for commercial macroalgae aquaculture in Norway were granted by public authorities in 2014 (Stévant et al., 2017). Since then, there has been a large increase in the number of both companies and granted permits, and as of February 2019, a total of 44 companies had been granted a total of 535 permits (Directorate of Fisheries, 2019).

Most of the macroalgae biomass being commercially cultivated in Norway today is used as food for human consumption. The waters along the Norwegian coastline are habitats to about 500 macroalgae species of which many can be utilised for this purpose. However, largely due to a current lack of cultivation methods for most of these species, only a few species are currently being commercially cultivated in Norway today. These include mainly the large kelp species sugar kelp (*Saccharina latissima*) and winged kelp (*Alaria esculenta*), due to relatively well-developed cultivation methods for these species, as well as their potential for high biomass yields and valuable nutritional content. However, several other species have been considered relevant for commercial aquaculture in Norway in the future (Broch, Skjermo, & Handå, 2016; Skjermo, 2016; Stévant et al., 2017).

The value chain
Different species may require somewhat different cultivation methods, and different applications of the biomass may call for both different cultivation and processing methods, and thus, different value chains (Broch et al., 2016; Skjermo et al., 2014). In the following, an illustration (Figure 1) and a presentation of a generalised value chain of the current (and potential future) Norwegian macroalgae aquaculture industry is provided.

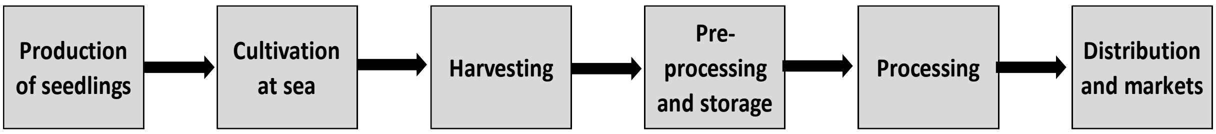

Figure 1: A generalised value chain of the current (and potential future) Norwegian macroalgae aquaculture industry (modified from Broch et al. (2016)).

Production of seedlings
Even though different macroalgae species may require different cultivation methods, most species require that the cultivation (more or less) follows their natural life cycle. Wild, fertile macroalgae produce spores which, after some time, are released to their surrounding waters. The released spores attach themselves to rocks or other forms of appropriate growth substrates, where they develop into juvenile seedlings, which further develop into mature macroalgae. Following this life cycle, the first part of the production of cultivated macroalgae in Norway involves land-based production of juvenile seedlings. The most widely used method for such production involves extraction of spores from wild macroalgae, which then are attached to appropriate growth substrates, usually thin ropes, and placed in incubators in laboratories with optimal growth conditions for development into juvenile seedlings (Broch et al., 2016; Skjermo et al., 2014).

Cultivation at sea
After one to two months in the laboratory, the ropes with juvenile seedlings are ready for transfer to the sea. Before deployed into the sea, these thin ropes are usually attached to thicker ropes, which then are fixed either vertically, horizontally or obliquely in the water, attached to floating rope frames moored to the seabed. Usually, seedlings produced in this way are deployed into the sea during the early winter months, and dependent on the geographical location on which they are being cultivated and the intended application of the mature macroalgae biomass, the biomass is usually harvested between April and June (Broch et al., 2016; Chapman et al., 2018; Skjermo, 2016).

Harvesting
When the mature macroalgae biomass is ready to be harvested, the harvest is usually done by cutting the biomass off from the ropes and loading it onto boats transporting it to land (Skjermo, 2016).

Pre-processing and storage
Fresh macroalgae biomass contains about 70-90 % water (Jensen, 1993), and is at risk of rapid microbial decomposition once harvested (Enríquez, Duarte, & Sand-Jensen, 1993). Therefore, application of appropriate preservation, or pre-processing, methods shortly after harvest to stabilize the biomass before storage, further processing and/or distribution to markets, is of great necessity. The most widely used methods for such pre-processing in Norway today are drying and freezing (Chapman et al., 2018; Stévant et al., 2018).

Processing
As macroalgae biomass produced for food purposes usually is eaten fresh or dried, there is really not a need for further processing of the biomass after pre-processing. However, to extract different micro level components from the biomass for use in a variety of applications as described above, specialised processing technologies (biorefineries) capable of extracting such components in a stepwise process, are required. Such technologies are not existing in Norway today, but are under research and development (Chapman et al., 2018; Skjermo et al., 2014).

Distribution and markets
Most of the macroalgae biomass cultivated in Norway today is traded to high-end restaurants using either fresh or dried biomass in their courses, or to food companies using the biomass as ingredients in food products. Currently, most of the biomass is traded outside Norway, mainly to Europe, because the Norwegian markets are still limited (Chapman et al., 2018; Godal, 2019).

2.2 The concept of sustainable development

According to Sachs (2015), *sustainable development* is both an analytical concept; a science or way of understanding the world, and a normative concept; urging us to have a vision of what a sustainable and good world should be. This subchapter elaborates on what this analytical (subchapter 2.2.1) and normative (subchapter 2.2.2) concept of sustainable development is all about.

2.2.1 Sustainable development as an analytical concept: An understanding of the world as a complex interaction of systems

The concept of sustainable development was first explicitly defined and popularized in 1987, in the now widely known report of the United Nation's (UN) World Commission on Environment and Development (WCED) named *Our common future*. In this report, *sustainable development* was defined as: "Development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED, 1987). It was emphasized that the concept encompassed three pillars; social, economic and environmental development – the triple bottom line – however, the pillars were largely seen as being separate from each other (WCED, 1987). Since then, there has been a significant evolvement of this analytical understanding and definition of the concept of sustainable development – into an understanding and definition which is now to a much greater extent based on *complex systems theory*.

Systems theory

Systems theory is the interdisciplinary study of systems, according to which a *system* can be defined as: "An integrated whole made up of a collection of interconnected and interacting components" (Merali & Allen, 2011). Systems theory was developed as a response to the growing recognition of the limitations of the traditional mechanistic and reductionist approaches dominant in the life sciences at that time, which were trying to understand living phenomena solely from the properties and behaviours of each of their components. In opposition to this, "the fathers" of systems theory argued that all living phenomena of the world can be seen as living systems consisting of interconnected and interacting components, and thus, that understanding not only the properties and behaviours of each of their components, but also the interactions between them, is essential to be able to understand the phenomena correctly and completely. They further argued that all such living systems share a number of features that should be the subject of a science of systems as such. Based on this, they proposed a framework of a 'general systems theory' able to be applicable in all levels and disciplines of life sciences, from the study of a single cell in biology to the study of whole human societies in social sciences – a framework that has come to enjoy widespread recognition and application within a variety of disciplines (Berkes, Colding, & Folke, 2003; Hammond, 2017; McKinlay & Williamson, 2010; Merali & Allen, 2011; Preiser, Biggs, De Vos, & Folke, 2018).

Complex systems theory
Systems theory is the interdisciplinary study of all types of systems, including so-called *non-complex systems* which are systems that may actually be viably understood by using traditional mechanistic and reductionist approaches. However, today, systems theory is mostly associated with the study of systems that have so-called *complexity* as an overall system characteristic, which means that these systems have a number of characteristic features that make traditional mechanistic and reductionist approaches insufficient to use to understand them correctly and completely. Complexity has been studied in a variety of disciplines, and concepts and ideas about it are often referred to as *complexity theory.* However, an a priori definition of complexity and a unified complexity theory do not exist, and the terms complexity, complexity theory, systems, and so-called *complex systems* and *complex adaptive systems* are often used interchangeably in the literature (Berkes et al., 2003; Cilliers, 1998; Preiser et al., 2018). Some theorists argue that complex adaptive systems are special cases of complex systems, however, the characteristic features that these theorists present as special for complex adaptive systems, differentiating them from complex systems, seem to be mostly the same features that other theorists present as special for complex systems, differentiating them from non-complex systems. Nevertheless, an overall understanding and vocabulary of complexity has emerged based on contributions from many different theorists, most of which is concerned with the characteristic features of systems having this overall system characteristic (Preiser et al., 2018). Largely based on theoretical contributions from Berkes et al. (2003), Cilliers (1998) and Preiser et al. (2018), the most significant of such features are presented in the following section, where the term *complex systems* is used when referring to systems having these features.

Large number of components
While non-complex systems consist of relatively few system components, complex systems are typically consisting of a very large number of components (Cilliers, 1998).

Presence of dynamic interactions
The large number of components must furthermore interact with each other and this interaction must be dynamic, for a system to be complex. The interactions do, however, not have to be of physical character, that is; in the form of exchanges of energy or matter, they may also be thought of as exchanges of information (Cilliers, 1998).

Richness of interactions
Complex systems are typically characterised by a great richness of interactions, which means that each component interacts with a quite large number of other components. The properties and behaviours of complex systems are, however, not determined solely by the exact amount of interactions associated with each of their components; if there is a sufficient number of components constituting a complex system, of which some are redundant, many sparsely connected components may be able to perform the same function as that of one richly connected component (Cilliers, 1998).

Short-ranging interactions but long-ranging influences
The interactions between the components of complex systems typically have a quite short range, which means that each component primarily interacts with neighbouring components in their local area. Nevertheless, due to the typical richness of interactions, the route from one component to any other can usually be covered in quite a few steps. One component, despite its short-ranging interactions, may therefore be able to have wide-ranging influences throughout a complex system (Cilliers, 1998).

Both one-way and two-ways non-linear interactions
In addition to one-way interactions leading influences from one component along many routes to many others, referred to as *feed forwards*, interactions in complex systems may also be two-ways due to loops in the interactions, referred to as *feedback loops*. This means that influences from one component can feed back onto itself, either directly or after several steps along a route. Furthermore, both one-way and two-ways interactions are typically of non-linear character, able to either dampen or amplify influences along their routes (Cilliers, 1998; Preiser et al., 2018).

Openness
A common feature of all types of systems is that their context is defined by an outer boundary, where the outside of this boundary is referred to as a system's *environment*. As opposed to *closed systems*, which are not interacting with their environment at all, most complex systems are *open systems*, which on the other hand typically are interacting with many components of their environment. The interactions between the system components and the components of the environment are typically also short-ranging but rich, and may be both one-way and two-ways. Such openness often makes it difficult to identify the boundaries of complex systems, and which components belong inside and outside these boundaries (Cilliers, 1998; Preiser et al., 2018).

Emergence
A core feature of complex systems is that this complex structure of a large number of single components and a large number of interactions both between the system components and between the system components and the components of the environment, makes the system as a whole able to exhibit properties and behaviours that none of the components are able to exhibit individually. This is referred to as *emergence*, making complex systems "more than the sum of their components" (Berkes et al., 2003; Cilliers, 1998; Preiser et al., 2018).

Structure around one out of multiple possible dynamic stable states
In complex systems, there must be constant exchanges of energy, matter or information through the interactions between the system components and between the system components and the components of the environment, for the systems to sustain the complex structure that gives rise to their emergent properties and behaviours. Complex systems are therefore typically structured around a so-called *dynamic stable state* where this structure is sustained. Such a state is far from a so-called *equilibrium state* where no exchanges of energy, matter or information are occurring due to a balancing of competing influences. However, the rich, dynamic and non-linear interactions allow not only one, but multiple possible dynamic stable states to exist for one single system. A system is typically structured around only one state at a time, but is able to transform from one state to another (Berkes et al., 2003; Cilliers, 1998; Preiser et al., 2018).

Self-organisation
An important reason why complex systems are able to transform from one dynamic stable state to another is that their rich, dynamic and non-linear interactions make them able to organise and re-organise their internal structure spontaneously, without the presence of any form of external control, nor any form of centralised internal control. This is referred to as *self-organisation*, and is a continuous process that occurs as a response to changes in the environment that through interactions with components of a complex system are causing changes and instability of the system's current structure.

If the system's feedback loops are not able to sustain this current structure, the system may re-organise the structure to achieve new dynamic stability in the face of these changes, potentially in such significant ways that the system may transform from its current to another of its possible states. A such significant transformation from one state to another is often referred to as a *regime shift*. The ability of a system to sustain a current structure and state in the face of changes represents an adaptive capacity of the system – however, self-organisation is also characterised as an adaptive process because the resulting new structures and potential new states may also be necessary to ensure the system's continued existence in the face of changes. It is also characterised as an adaptive process in the sense that resulting new structures and potential new states are also dependent on internal factors such as both a system's past history and its current structure and state (Berkes et al., 2003; Cilliers, 1998; Preiser et al., 2018).

Learning and representation
The reason why complex systems have adaptive capabilities is that they are able to gather, store and learn from information about the environment for future use. This information is used to make the systems' structures and states "meaningful" in the sense that they are somehow representing the information that is important to the systems' continued existences, as determined by their past history, their current structure and state, and changes in the environment. Together with feedback loops and self-organisation, such *learning* and *representation*, make complex systems able to be constantly evolving and adapting over time (Cilliers, 1998; Preiser et al., 2018).

Non-linearity and uncertainty
Even though there is a "meaning" or "reason" behind the dynamics of complex systems, the dynamics are nevertheless typically very difficult to predict. This is due to the *non-linear character* of the interactions of complex systems, which causes their responses to changes also to be of *non-linear character*, which means that the magnitude of their responses is disproportionate to the magnitude of the changes causing these responses. This means that large changes may produce only small responses, while small changes may be able to cause a system to go through a whole transformation from one state to another. Typically, this is because each of a system's possible states has its own system-dependent threshold level for how large changes the system can handle and still sustain the current state. Thus, if a large change occurs but the change is below this threshold level, feedback loops will make the system able to absorb the change and sustain the current state. However, if so an additional small change occurs, and, due to the history of changes, this makes the total changes so large that the threshold level is being transgressed, the system will not be able to sustain its current state, and may rather significantly re-organise its structure and transform both rapidly and dramatically from its current to another of its possible states. A such rapid and dramatic regime shift is often referred to as a *flip*, and is, as implied, typically very difficult to predict (Berkes et al., 2003; Cilliers, 1998; Levin et al., 2013; Preiser et al., 2018).

Several levels of scale
A last important feature of complex systems is that they typically have several levels of scale, which means that one complex system may consist of a number of smaller subsystems, where each of these subsystems in turn may consist of a number of even smaller subsystems. The subsystems at each scale may have their own emergent properties and behaviours, but they are typically coupled together through feedback loop relationships (Berkes et al., 2003; Preiser et al., 2018).

Towards an understanding of the word as a complex interaction of systems
The features of complex systems are applicable to a wide range of different systems, and complex systems theory has come to enjoy widespread recognition and application within a variety of disciplines, including within disciplines of environmental sciences to understand the Earth's natural environment and its complex natural systems, and within disciplines of social sciences to understand humans and our complex social systems. However, until quite recently, different disciplines of environmental sciences were largely studying different natural systems separately, having limited contact with each other, and the contact between environmental sciences and social sciences was also limited (Berkes et al., 2003; Preiser et al., 2018). However, this started to change some decades ago, largely as a result of a growing body of research that gave rise to two fundamentally new perspectives on the world. Firstly, research showed that different natural systems of the Earth's natural environment are interconnected and interacting, suggesting that we should have a perspective on the Earth's natural environment as one complex system consisting of many different subsystems, and thus, that these subsystems should be studied in relation to each other instead of separately. Secondly, research showed that humanity as a whole, with all our social activities and systems, since the Industrial Revolution has been affecting the Earth's natural environment in such profound ways that scientists argue that the world now has been pushed out of the past 10.000 year-long geological epoch known as *the Holocene*; an epoch where the whole complex Earth system were kept in a dynamic stable state with conditions that enabled human development, and into a new geological epoch referred to as *the Anthropocene*; an epoch where humanity now is changing the structure of components and interactions that keep the complex Earth system in this state that further human development and prosperity is dependent on. This has given rise to a further new perspective on humanity as a whole, with all our social activities and systems, as integrated parts of, and not separate from, the whole complex Earth system, both shaping all aspects of natural systems and at the same time being fundamentally dependent on them (Steffen et al., 2004). Based on this perspective, the concept of *social-ecological systems* has further risen, emphasising that social and natural systems are so strongly interconnected and interacting that they should not be regarded as separate from each other, but as integrated complex subsystems, or components, of the whole complex Earth system (Berkes & Folke, 1998).

One of the most well-recognised contributions to sustainability science the last years showing that different natural systems of the Earth's natural environment are interconnected and interacting and that humanity now is about to change these systems and push the whole complex Earth system out of the dynamic stable Holocene state, is the *Planetary Boundaries (PB) framework*, first published by Rockström et al. (2009). The framework describes nine *planetary boundaries* for nine processes, or subsystems, of the whole complex Earth-system; climate change, biodiversity loss (genetic and functional), land-system change, freshwater use, altered biogeochemical cycles (nitrogen and phosphorus), ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, and novel entities (chemical pollution). The boundaries define 'the safe operating space' for humanity with regards to be keeping the Earth system in the dynamic stable Holocene state because if the boundaries are transgressed, these processes can generate dramatic system changes pushing the Earth-system out of this state. The boundaries of the processes of climate change and biodiversity loss are regarded as *core boundaries*, because transgressing these boundaries can, on their own, drive more significant changes than transgressing those of the others can. However, the framework emphasises at the same time that all the nine processes are interconnected and interacting, and thus, that they are influencing each other, which means that all the processes are important and should be considered in relation to each other (CISL, 2019; Rockström et al., 2009). Since the first proposal of the framework in 2009, an update of the framework published in 2015 showed that four of the boundaries already have been transgressed as a result of human activities; climate change, biodiversity loss, land-system change, and altered biogeochemical cycles (Figure 2), implying that, if the Earth system is to be kept in the dynamic stable Holocene state, no additional pressures should be put on these processes – conversely, they should be reversed (Steffen et al., 2015).

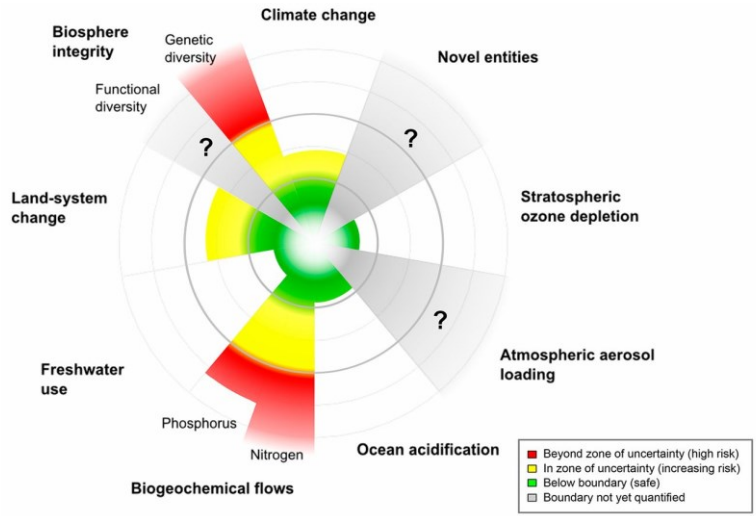

Figure 2: The current status of the Planetary Boundaries framework (Steffen et al., 2015).

Through the work with formulating a new proposal to the normative side of the concept of sustainable development (see subchapter 2.2.2), Griggs et al. (2013) argued that our understanding and definition of sustainable development should be based on this integrated whole complex Earth system perspective regarding humans and our social systems as integrated with the Earth's natural environment and its natural systems, and the recognition that this integrated whole complex Earth system must be kept in the dynamic stable Holocene state for further human development and prosperity to be enabled. Based on this, they argued that sustainable development should not be understood as being consisting of separate pillars, but rather as being an integrated concept regarding the economy as serving the society, which in turn depends on the Earth's natural life-support system as enabled by the dynamic stable Holocene state. Further based on this, they proposed a re-definition of sustainable development to: "Development that meets the needs of the present while safeguarding the Earth's life-support system, on which the welfare of current and future generations depends" (Griggs et al., 2013). On the analytical side, the concept of sustainable development evolved with this into an understanding of the world as one whole complex system consisting of three interconnected and interacting subsystems; the social systems of the economy and the society, and the Earth's natural environment. In this understanding, the sustainability of the Earth's natural environment was assigned a fundamentally more important role than before, exactly due to its fundamentally important role for the sustainability of the whole complex Earth system also including humanity and our social systems (Griggs et al., 2013).

To understand how to keep the whole complex Earth system in the dynamic stable Holocene state and enable further human development and prosperity, the concept of *resilience* has become essential. Today, this concept is understood as the ability of any living system, from a single cell to whole social-ecological systems, to handle changing conditions, both in the sense of being able to absorb changes and sustain a current dynamic stable state, but also in the sense of being able to continue to exist and evolve while undergoing change. The latter involves the ability to learn from and adapt to new opportunities that changes opens up for, in the sense of re-organisation and renewal of the system, even to the point of transgressing threshold levels and transforming into new states and new development trajectories, if this is what makes "the best match" between the system and their environments. This means that resilience today is understood as an integration of absorptive, adaptive and transformative abilities of systems (Folke, 2016). The concept of resilience has become essential within sustainability science because it is argued that to sustain the resilience of the whole complex Earth system at a global level, in the sense of keeping the system in the dynamic stable Holocene state essential for further human development and prosperity, resilience in the sense of both adaptability and transformations of social-ecological systems at regional and local levels towards new development trajectories instead of keeping "business-as-usual" is needed. Based on this, sustainable development can be regarded as a continuous dynamic process that requires high resilience of both the whole complex Earth system at a global level and of social-ecological systems at regional and local levels, in the face of continuously changing conditions (Berkes et al., 2003; Folke, 2016).

To be able to support resilience and ensure sustainable development of both the economy, the society and the Earth's natural environment altogether, it has further been emphasised that good governance by major social actors such as governments and businesses is of fundamental importance. This has thus led to an extension of the concept of sustainable development into an understanding of the world as one whole complex system consisting of not only three, but four interconnected and interacting subsystems, additionally including the governance system as the fourth subsystem (Sachs, 2015). This evolvement and new analytical understanding of the concept of sustainable development has, as implied, constituted the basis for a new proposal to the normative side of the concept; *the UN's Sustainable Development Goals* (SDGs) (United Nations, 2020m).

2.2.2 Sustainable development as a normative concept:

The Sustainable Development Goals for a sustainable and good world

On the normative side, the concept of sustainable development urges us to have a vision of what a sustainable and good world should be, by defining a set of goals for a sustainable and good world to which we should aim for (Sachs, 2015). Today, this set of goals is known as *the UN's Sustainable Development Goals (SDGs)* (Figure 3), which builds upon a previous set of goals known as *the UN's Millennium Development Goals (MDGs)*. Lying at the heart of *the 2030 Agenda for Sustainable Development* that was adopted by all UN's member states in 2015, the SDGs are to be implemented by all countries and stakeholders, acting in collaborative partnership, to be achieved by 2030 (SDSN, 2015).

Figure 3: The Sustainable Development Goals (United Nations, 2020m).

Based on the analytical understanding of the world as one whole complex system consisting of four interconnected and interacting subsystems, the SDGs, defining goals for this whole world, are regarded as one complex whole consisting of many interconnected and interacting goals and targets, which together define four overarching goals for the four subsystems; economic prosperity, social inclusion, environmental sustainability and good governance – which all are essential dimensions of a sustainable and good world (Sachs, 2015). In line with the theory about these real-world complex systems upon which this analytical understanding is based, the interactions between the interconnected goals and targets of the SDGs are able to produce emergent, non-linear effects in the form of both *positive synergies* and *negative trade-offs* between the goals and targets. For the most part, they produce positive synergies, which means that progress on one goal or target is a prerequisite for, or leads to, progress on others. However, they may also produce negative trade-offs, which means that progress on one goal or target may lead to negative effects on the progress on others. Therefore, understanding and considering such interactions when implementing the SDGs is essential to minimise trade-offs and ensure that progress made in some areas is not made at the expense of progress in other areas, as well as to maximise synergies and unlock the SDGs' full potential at any scale. However, it is emphasised that it is important to have a nuanced view of the interactions; seeing not only synergies or trade-offs, but several different types of interactions in between these "extremities", as they may have quite different implications in terms of implementation action (ICSU, 2017).

2.3 Business contributions to sustainable development

For many years, the business sector has been regarded as a major contributor to both economic, social and environmental problems, and to be prospering at the expense of the broader society and environment (Porter & Kramer, 2011). Based on this, but also on an increasing recognition that businesses are also in a position to create positive effects and solutions to sustainable development aspects, the SDGs are, as opposed to the MDGs, explicitly encouraging the business sector to implement the SDGs as a framework for their business strategies and to apply their creativity and innovation to contribute to sustainable development both by minimising negative impacts and by creating and maximising positive effects and solutions (GRI, UN Global Compact, & WBCSD, 2016). There are many ways the business sector can do this, but recognising and understanding that companies and whole industries can be regarded as subsystems, or components, of larger social-ecological systems, being interconnected and constantly interacting with other subsystems or components of such systems, is fundamental anyhow. Based on such a recognition and understanding, aiming for *strategic corporate social responsibility (CSR)* and *shared value creation*, is further essential.

Strategic corporate social responsibility and shared value creation
Historically, the concept of *corporate social responsibility (CSR)* has generally been understood to be mostly about a company's social responsibility to its local community. Even though many companies are still focused on this understanding, the concept has, however, generally evolved and extended over time; now being understood as a tool for the business sector to contribute to sustainable development in a much more holistic manner; now involving taking both social, economic and environmental responsibility (Fet & Knudson, 2017). However, even though many companies are doing a lot to contribute to sustainable development through their CSR work, their contributions have often potential to be a lot more productive. According to Porter & Kramer (2006), this is because many companies are taking a *responsive* CSR approach, which means that they attempt to "do good" by considering and being responsive to stakeholder concerns, and by minimising negative impacts of their activities. By taking this CSR approach, companies typically have a view that there are only negative conflicts or trade-offs in the interactions between their company and the society and environment, and regard CSR as a generic concept to be used to defend themselves against creation of competitive disadvantages, instead of something that can be adapted specifically to their company for creation of competitive advantages. Consequently, even though this approach may make them contributing to sustainable development to a certain extent, the companies are often not able to identify, prioritise, and address the aspects that matter the most or the ones to which they can make the greatest positive contributions. To contribute to true, holistic sustainable development in a much more productive way, Porter & Kramer (2006) emphasise that companies should rather take a *strategic* CSR approach, which means that they should not only focus on conflicts or trade-offs and try to minimise negative impacts, but go beyond this and also recognize and focus on the positive synergies lying in the interactions between their company and the society and environment, and try to create competitive advantages by connecting their economic success with social and environmental progress, and creating and maximising such positive effects for both their company and the society and environment. That is; to create and maximise *shared value* (Porter & Kramer, 2006, 2011). By aiming for such shared value creation, companies and industries can play a key role in contributions to the SDGs and development into a sustainable and good world (GRI, UN Global Compact, & WBCSD, 2016).

2.4 Modelling sustainability as a complex interaction of systems

A model of sustainability, for example of an industry which is the purpose of this study, can be of great usefulness to get overview of, understand, and be able to productively address and create solutions to aspects that truly are of importance for achieving true, holistic sustainability. As sustainability is regarded as a science of complex systems, it is argued by many that it is necessary to take a complexity-based approach towards modelling of it, in order for such a model to be truly representative and useful. According to Peter & Swilling (2014), and others, this means that a modelling approach must be *integrative, probabilistic, adaptive* and *inclusive.*

Integrative
For a modelling approach to be *integrative*, it must integrate between relevant real-world social-ecological systems and their components and reflect the characteristic complex interconnection and interaction between these, across different levels of scale. This integration should further be of an *heterarchical* character, which means that the integrated systems and components of a model are organised in a flat structure not specifying the importance, weight, or value attached to individual components or their combination, and are able to be re-organised according to changes and evolvement of the real-world systems that are being modelled. This is thus important for a model to accommodate learning and to be flexible and adaptive (Peter & Swilling, 2014).

Probabilistic
For a modelling approach to be *probabilistic*, it must embrace methodologies based on probability theory, in order for a model to account for and accommodate non-linearity, uncertainty, and multiple possible stable states and scenarios, also characteristic of real-world complex systems. This is also required for a model to accommodate learning and to be flexible and adaptive to real-world system changes (Peter & Swilling, 2014).

Adaptive
A modelling approach to sustainability must, as implied above, further be *flexible* and *adaptive*, allowing a model to be able to be quickly adapted to real-world system changes as they occur, based on learning. This is not the least important in the context of modelling to support management and decision-making, which also should be flexible and adaptive processes based on learning (Berkes et al., 2003; Peter & Swilling, 2014).

Inclusive
Because of its complexity, sustainability can be best understood by use of a multiplicity of perspectives. A modelling approach towards sustainability should therefore lastly be *inclusive*, which means that it should embrace multi-participant modelling processes, accommodating multiple and diverse perspectives from both scientists, decision-makers and other stakeholders. This is important for shared, holistic understanding, and to stimulate learning and adaptive capacity (Berkes et al., 2003; Peter & Swilling, 2014).

These four key considerations have been important for the choice of methodology used to achieve the objectives of this study, including both the choice of making use of the Wheel of Sustainability for salmon aquaculture (WOS-SA) as a basis for modification to make this model be specifically applicable to the macroalgae aquaculture industry, and other parts of the methodology. The WOS-SA is presented and described in the next subchapter, while the complete methodology used in this study is described in chapter 3.

2.5 The Wheel of Sustainability for salmon aquaculture

Given the importance of having a holistic, complexity-based perspective on sustainability, and thus, to take a holistic, complexity-based approach towards modelling of it, Osmundsen et al. (2020) recently developed the Wheel of Sustainability (WOS) – in this thesis referred to as the Wheel of Sustainability for salmon aquaculture (WOS-SA) – as such a holistic, complexity-based model of sustainability of salmon aquaculture.

The model as holistic and complexity-based

The WOS-SA can be characterised as holistic and complexity-based because it has largely been developed by use of an integrative, probabilistic, adaptive and, to a certain extent, inclusive modelling approach, thus reflecting the concept of sustainability of the salmon aquaculture industry in a representative and useful way. Firstly, the model is largely integrative, in the sense that it integrates between four main sustainability domains representing four main systems of the world considered of importance for understanding and achieving true, holistic sustainability of the salmon aquaculture industry; the 'Environmental', 'Economic', 'Cultural' and 'Governmental' domain. Each of these domains are in turn consisting of seven subdomains designed to be capturing the overall key aspects of each domain. The domains and subdomains are presented separately, but are at the same time described as being interconnected and interacting, and must be seen in relation to each other to account for these interactions and potential negative trade-offs and positive synergies lying in them. The creators of this model have, however, chosen to base the model on a somewhat different understanding of sustainability than the common understanding of sustainability as a science of the environmental, economic, social and governmental system. Instead, it is based on an understanding of sustainability that emphasises that humanity and all our social activities and systems are the whole reason why there is a need for the concept of sustainability at all, something which is particularly obvious when dealing directly with sustainability of an human activity such as operating an industry. In this context, the social domain therefore encompasses humanity and our social activities and systems, and is kind of underpinning the whole model. The four main sustainability domains of the model are thus all parts of this underpinning social domain, representing different aspects of humanity and our social activities and systems being of importance for sustainability, here in the context of the salmon aquaculture industry (Osmundsen et al., 2020).

Further, the WOS-SA integrates the four main sustainability domains and their pertaining subdomains in a heterarchical structure not specifying the importance, weight, or value attached to individual domains or subdomains or their combination. The domains and subdomains are furthermore not mutually exclusive, and they are described in general terms. The fact that they are not mutually exclusive allow for inclusion of all relevant aspects of specific topics in the model. The creators of the model explain this by exemplifying how different aspects of the topic of labour aspects are encompassed by three different subdomains in the model: 'Labour & employment' ('Economics') concerning economic compensation for labour, 'Social assurance' ('Governance') concerning basic rights of employment, and 'Employee interests & well-being' ('Culture') which transcends these basic rights and includes aspects such as development of expertise. The general descriptions further allow the model to be universal and able to include additional aspects that are either already existing but not mentioned explicitly in the model, or maybe even not discovered or existing yet. In this sense, the model is also largely probabilistic, flexible and adaptive, able to accommodate uncertain real-world scenarios and changes as they occur, based on learning (Osmundsen et al., 2020).

When it comes to the last element; that a modelling approach towards sustainability should be inclusive, the WOS-SA was developed by a multidisciplinary research team consisting of scientists from different fields having in-depth competence and perspectives on salmon aquaculture from their respective fields – however, the team included only scientists, and no decision-makers or other stakeholders (Osmundsen et al., 2020). In this sense, the modelling approach cannot be characterised as completely inclusive – however, as eight different sustainability standards for salmon aquaculture covering different parts of the value chain and developed by a number of different types of stakeholders connected to this industry constituted a main part of the data basis used to develop the model (see description of the modelling process below) the modelling approach can in this sense still be characterised as inclusive.

The modelling process

The purpose of the study that created the WOS-SA was to assess the scope of eight different sustainability standards for salmon aquaculture, which cover different parts of the value chain of this industry and are developed by a number of different types of stakeholders connected to this industry, in their operationalisation of sustainability. In this context, the WOS-SA was developed to provide a holistic reference basis according to which the standards could be assessed. With this as a background, the model was developed through an iterative process between workshops with deliberations among the multidisciplinary research team aiming to identify all relevant sustainability aspects of salmon aquaculture, and several coding processes where the indicators of the standards where coded according to the preliminary version of the model aiming to verify, refine or disprove it. When the final version of the model was finished, the indicators were coded according to it a last time, to assess the scope of the standards in their operationalisation of sustainability. This means that the indicators of the standards were used both as a main data basis for developing the model, and as data for assessment according to the final model (Amundsen & Osmundsen, 2018; Osmundsen et al., 2020).

The Wheel of Sustainability for salmon aquaculture

In the following, the complete WOS-SA created by Osmundsen et al. (2020) is presented.

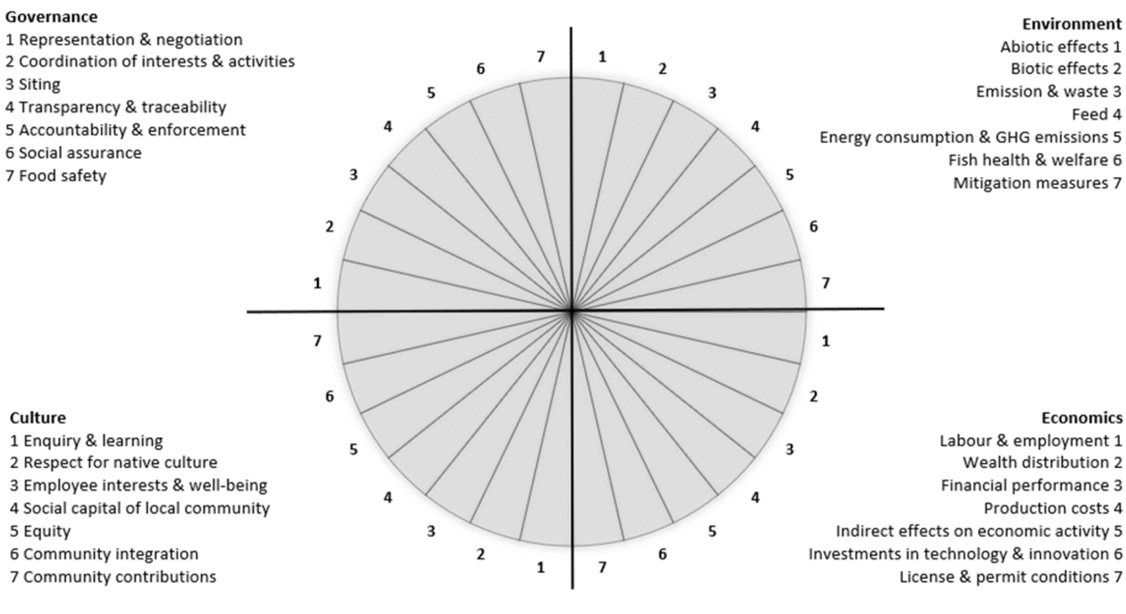

Figure 4: The Wheel of Sustainability for salmon aquaculture (WOS-SA) (modified from Osmundsen et al. (2020)).

2.5.1 Environment

Environment includes the practices, discourses and material expressions that occur across the intersection between the social and natural realms. The natural realm includes a spectrum of environmental conditions, from the untouched to the modified. This domain thus focuses on the questions of social-environmental interconnection, including the human impact on and place within the environment.

Abiotic effects
This subdomain includes how impacts on local habitat and water quality are assessed, and whether key environmental variables, such as terrestrial, seabed, and water resources are continuously monitored, and subsequent preventive or corrective actions.

Biotic effects
This subdomain includes how impacts on native species are assessed, whether biodiversity in the surrounding areas is continuously monitored, and means to ensure limited interaction with wildlife, such as measures to prevent escapes. Biodiversity includes birds, mammals, fish and bottom fauna.

Emission & waste
This includes the assessment of environmental impacts caused by production waste and pollution through mortality, feed, the use of chemicals, etc. Further, it relates to what extent biological and non-biological waste is handled in a proper and responsible manner, through for instance recycling.

Feed
This subdomain includes the composition and traceability of raw materials in feed as well as the efficiency of how the salmon is fed. Examples of indicators are feed factor, use of trimmings, and fishmeal/Fish Oil Forage Fish Dependency Ratio.

Energy consumption & GHG emissions
This includes assessment of efficient and sustainable use of energy, and continuous monitoring of emissions throughout the production chain.

Fish health & welfare
Measures taken by the aquaculture company to ensure the health and welfare of salmon and cleaner fish. This subdomain includes monitoring of diseases and parasites, vaccines, therapeutic treatments, extent of mortalities, etc.

Mitigation measures
This subdomain includes the existence of contingency plans, clean-ups, emergency plans, and established routines to deal with potential mishaps.

2.5.2 Economics

Economics includes the practices, discourses and material expressions related to production, use and management of resources for seafood production. This domain contains direct measures of economic sustainability such as firms' financial return on investment, as well as economic effects on a larger scale to capture the impact of the production activity on the surrounding society.

Labour & employment
This subdomain includes indicators that measure the relative level of salaries compared to the local, regional or national level, required skills or competence, and the availability of jobs. This refers also to the permanency vs. seasonal positions.

Wealth distribution
Distribution of wealth encompasses how the aquaculture company distributes its wealth in the local, regional or national community. Municipal taxes may be one such indicator.

Financial performance
The financial performance of the aquaculture company as measured by several possible indicators, e.g. profits, EBIT, EBIT/kg, ROI, ratio between production and mortality/loss, and difference between price and total cost (excl. salaries).

Production costs
This subdomain includes indicators that refer to different aspects of production costs, such as feed, transportation, slaughtering, labour, investment, capital and access to credit, but also environmental monitoring and measurements. It refers to the cost of treatment of diseases and parasites, such as vaccines, therapeutic treatments, non-medical treatments and veterinary services.

Indirect effects on economic activity
The aquaculture company may make investment in public infrastructure that benefits the local community, e.g. roads, buildings, piers, slips, broadband, and housing. This subdomain also includes ripple effects such as local businesses established throughout the supply chain, e.g. net-makers/cleaners, smokehouses, supply and waste management, or other businesses funded by aquaculture money.

Investments in innovation & technology
This subdomain includes investments done in research and innovation projects which may lead to development of new technology.

License & permit conditions
This subdomain encompasses the conditions pertaining to how licenses and permits are obtained by the aquaculture industry, including price, length of the permit, type of ownership, and conditions of rent, as well as conditions for production set in obtained licenses and permits.

2.5.3 Culture

Culture is the part of the social domain that emphasizes the practices, discourses and material expression that over time express the continuities and discontinuities of social meaning of a life held in common. Culture is understood as how and why we do things around here.

Enquiry & learning
This includes the company's engagement in research and development. This can be realized through the collaboration on behalf of the aquaculture company with the local community, schools, universities or others for research, knowledge-building and dissemination purposes.

Respect for native culture
This subdomain is about ensuring that the company's activities respect, value and promote the ancestral culture of the region, as many aquaculture operations are placed in areas that are claimed as traditional territories or where indigenous groups are present. This includes entering into dialogue, and establishing agreements with such groups.

Employee interests & well-being
This includes how the company ensures the well-being of the employees through initiatives such as development of expertise, career advancement opportunities, language and integration courses for foreigners, social events, etc. Also procedures for conflict resolution between workers and between employer/employees are included.

Social capital of local community
This subdomain includes how the aquaculture company attempts to sustain and promote the social capital of the community, or in other words, the social fabric of the community, e.g. resources, relationships, social networks, and adaptive capacity. Elements of this may be expressed in the form of a social license.

Equity
This includes how the company may be seen to be upholding and improving the social structures and collective capabilities of the local community, such as gender equality, age non-discrimination, and by ensuring a generational approach. Equity emphasizes how the industry, alongside public efforts, are seen to meet the needs of groups in the local community.

Community integration
Community integration is about fostering a sense of identity between the company and the local community, and about taking initiatives to make the employees feel integrated in the company and creating a sense of belonging.

Community contributions
This subdomain includes how the aquaculture company can be seen to contribute to the local community by e.g. donating money to local communities, e.g., schools, sport teams, events, or by hosting or sponsoring events.

2.5.4 Governance

Governance is the part of the social domain that emphasizes practices and meaning related to how public goods and services are provided and regulated. This refers to basic issues of social power as they pertain to the organization, authorization, legitimation and regulation of a social life held in common. It includes how the industry is regulated on a national level, but encompasses also the norms and practices initiated on a local and company level.

Representation & negotiation
This subdomain includes the presence and influence of stakeholders facilitated through available forums where different interests and concerns can be communicated and discussed. It also contains the encouragement of participation and inclusion of the local community through access to information regarding the company's operations, intentions, and plans. Resources and capacity to receive and process criticism and complaints, and evidence of how such conflicts are handled is also encompassed by this subdomain.

Coordination of interests & activities
This includes the coordination with other activities in the area, such as fisheries, recreation, and tourism, such as planning capacity and willingness to deal with conflicts from multiple uses of marine space and resources, e.g. conflicts of interest, displacement of other activities, and general loss of amenity. Also, collaboration and coordination with nearby aquaculture facilities and their production is included. Participatory marine spatial planning, as instigated by government or by shared agreement, is also underneath this subdomain.

Siting
This subdomain includes how the siting process of an aquaculture location is undertaken, referring to the geographical location of the site. It encompasses how local communities and other stakeholders are consulted and heard, whether protected areas and waterways with migrating salmon is considered, and whether assessment and knowledge about nearby eco-systems are included into the planning process.

Transparency & traceability
This subdomain includes how the aquaculture company allows for openness surrounding daily operations, and the decision-making process. This also includes the accessibility and circulation of information, both on own initiative and on request. Additional information may include e.g. degree of accessibility, available information channels, choice of language, and format. Both internal transparency within the company and external transparency towards the public, as well as record-keeping are part of this subdomain.

Accountability & enforcement
This includes knowledge of and compliance with all applicable national and local rules and regulations by the aquaculture company, as well as enforcement and sanctions when rules and regulations are not followed. Whether or not the company has internal requirements to behaviour, and/or internal audits is also included.

Social assurance
This subdomain includes upholding the rights of employees, based on national regulations and as stated by the International Labour Organization (ILO)– e.g. freedom of association, contracts, working hours, equality in hiring process, and no discrimination. Health and safety is also included here, meaning requirements of use and availability of personal protective equipment, as well as necessary training. An emphasis on upholding a safety culture through training, health plans, and a focus on potential risks in procedures and contingency plans is encompassed.

Food safety
This subdomain includes how food safety is ensured throughout the production chain. This may be done through for instances procedures, HACCP, quality systems and risk assessments.

2.6 The ASC-MSC Seaweed Standard

Sustainability certification has become increasingly important within aquaculture production, aiming to assure consumers that the products they purchase are produced in sustainable manners. Within the salmon aquaculture industry, this has led to a multitude of sustainability schemes and standards, encompassing a multitude of indicators and requirements for salmon aquaculture (Osmundsen et al., 2020). Within the very young macroalgae aquaculture industry, only one industry-specific sustainability standard is, however, currently existing; *the ASC-MSC Seaweed Standard* (ASC & MSC, 2018). This standard is developed by the two international sustainability certification bodies for seafood; *Aquaculture Stewardship Council (ASC)* and *Marine Stewardship Council (MSC)*, which certifies seafood from aquaculture and fisheries, respectively. The standard is developed to reward sustainable macroalgae production globally, applying to both macroalgae aquaculture and macroalgae harvest. It is focused on environmental and social sustainability and provides a number of criteria for these sustainability aspects, according to which production units are to be assessed and potentially certified for compliance with (ASC & MSC, 2018). Based on this, it was considered that this standard could provide valuable information about specific important sustainability aspects of macroalgae aquaculture, and it was therefore included as a source of data used in the process of modifying the WOS-SA to be specifically applicable to the macroalgae aquaculture industry. The review and consideration of the themes and indicators of this standard to identify such important sustainability aspects is presented in the next chapter describing the complete methodology used in this study.

3 Methodology

This chapter describes the methodology used for achieving the objectives of the study presented in this thesis. As the Wheel of Sustainability for salmon aquaculture (WOS-SA) was used as a basis for modification to make this model be specifically applicable to the macroalgae aquaculture industry consistent with objective 2, this methodology is, to a certain extent, based on the methodology used in the study that created the WOS-SA, conducted by Osmundsen et al. (2020). Subchapter 3.1 of this chapter is therefore providing a brief overview of the whole research process of the study presented in this thesis and how this process is similar to, and how it differs from that of the study of Osmundsen et al. (2020). Subchapter 3.2 and 3.3 elaborate on the processes of conducting several qualitative semi-structured interviews with relevant actors from science, public administration and the industry, and a systematic literature review, respectively, which constitute the main methods for data collection in this study. Subchapter 3.4 further elaborates on how the collected data were analysed and used to modify the WOS-SA to make this model be specifically applicable to the macroalgae aquaculture industry. Subchapter 3.5 describes ethical issues connected to this study and how these have been addressed.

It is important to note here that I, the researcher of this study, have been in regular contact with the creators of the WOS-SA during the whole research process, to get as correct information about the WOS-SA as possible, and for regular validation of how the WOS-SA has been used and presented in this study and thesis.

3.1 The research process

The study presented in this thesis was conducted through a similar, but not quite identical research process as that of the study conducted by Osmundsen et al. (2020) (see subchapter 2.5 for an overview of their research process). Firstly, instead of starting "all from scratch" like Osmundsen et al. (2020) did, this study did, as already mentioned, make use of the WOS-SA created by Osmundsen et al. (2020) as a basis for modification to make this model be specifically applicable to the macroalgae aquaculture industry. This means that the WOS-SA was used both as an initial source of data providing a set of already identified sustainability aspects potentially being just as important for the macroalgae aquaculture industry as for the salmon aquaculture industry, and as a framework for the process of analysing and coding the rest of the data about sustainability of the macroalgae aquaculture industry collected later in the study – data which potentially would indicate a need to modify the WOS-SA to make it be specifically applicable to this industry. The reasons why the WOS-SA was used as such a basis was, firstly, the recognition that this model seems to be modelling the concept of sustainability of an industry in a very representative and useful way managing to reflect its overall complexity, and that it therefore viably can serve as such a basis for development of models of sustainability of other industries. Actually, the creators of the WOS-SA have explicitly stated that it is their wish that their model can be used in this way. Furthermore, based on the recognition that the macroalgae aquaculture industry and the salmon aquaculture industry can be regarded as related industries having several general similarities arising from both being aquaculture industries, it was considered that some parts of the WOS-SA probably would be of particular relevance for the macroalgae aquaculture industry compared to other, more different industries. Taken all together, it was considered that the use of the WOS-SA as a basis for modification would serve as a quality assurance of the resulting new model of this study.

Secondly, instead of arranging workshops like Osmundsen et al. (2020) did, the main methods for data collection in this study aiming to identify important sustainability aspects of the macroalgae aquaculture industry included several qualitative semi-structured interviews with relevant actors from both science, public administration and the industry, and a systematic literature review. However, in a kind of similar way as Osmundsen et al. (2020) did with the eight sustainability standards for salmon aquaculture, this study did also make use of a sustainability standard; the ASC-MSC Seaweed Standard, as an additional source of data for developing the new model. The data obtained from the interviews, the literature review and the ASC-MSC Seaweed Standard were then analysed and coded according to the WOS-SA, and used to modify this model to be specifically applicable to the macroalgae aquaculture industry.

This means that the data used to modify the WOS-SA were collected from several different data sources by use of mixed methods. The reason for doing this is that the use of such different data sources and mixed methods is recommended to get as holistic, complete and correct data as possible (Alexander, Thomas, Cronin, Fielding, & Moran-Ellis, 2008). In the following sections, the different parts of the data collection and methodology are further elaborated.

3.2 Qualitative semi-structured interviews

As the purpose of this study has an explorative and qualitative character aiming to identify, synthesise and develop a kind of theory about qualitative aspects of a complex field being relatively unexplored from before, a qualitative data collection method in the form of qualitative semi-structured interviews were considered appropriate to use as the main method for collecting information about important sustainability aspects of the macroalgae aquaculture industry in this study. This type of interview is one of the three main types of interviews, synthesising "the best" of the two other main types; structured and non-structured interviews. When conducting semi-structured interviews, the interviewer ask the same main questions in each interview in kind of a similar way as when conducting structured interviews, but the questions are typically more open-ended and the interviewer is also free to alter the sequence of the questions and probe for more information in response to the answers from the interviewees, more like the approach being used when conducting non-structured interviews. This is allowed through use of an interview *guide,* instead of an interview *schedule* being used in structured interviews. This has several positive advantages. Firstly, the "structured part" of a semi-structured interview make the interviewer able to collect information about a desired set of topics from several different interviewees, and to compare the different interviews afterwards. On the other side, the "non-structured" part make the interviewer able to adapt the interview to the interviewee's level of comprehension and articulacy, and to follow up and probe for more information about relevant aspects that may emerge during the interview (Fielding & Thomas, 2008). The interviews conducted in this study had, however, some more of a non-structured character than may be the case of a typical semi-structured interview. They did contain a set of main questions asked in each interview, but most of the questions were formulated very open-ended, allowing the interviewees to talk relatively freely about what aspects they considered important, and to provide rich, thick descriptions of these. This was done because such a type of qualitative data collection method is valuable exactly when the field of matter is complex, and it can additionally make central contributions to theory development. The latter is so because open-ended formulations provide a safeguard against the risk of "seeing what you are already believing" which is often connected to more structured methods, and provision of rich, thick descriptions of real aspects allows for stimulation of deeper thought and new insights that can both be related to existing theories and also allow one to create new theoretical insights (Doz, 2011). The interview guide with the questions asked in the interviews conducted in this study can be found in Appendix A. It is important to point out here that the questions about regulation and standardisation which can be found in this interview guide primarily were asked to be able to conduct an assessment of the scope of the ASC-MSC Seaweed Standard in its operationalisation of sustainability, which was an initial objective of this study. However, this objective was later excluded from the study (see subchapter 1.2), and several of these questions can therefore be regarded as (more or less) irrelevant. Nevertheless, the data obtained from these questions contributed to give a thorough understanding of the macroalgae aquaculture industry and its associated sustainability aspects, something which has been valuable for the study.

The sample of interviewees that was interviewed in this study consisted of 15 relevant actors with in-depth competence on the Norwegian macroalgae aquaculture industry, from both different parts of the industry, different roles within public administration and different disciplines within science. This heterogenic sample was a strategic choice made to make the modification of the WOS-SA an inclusive process, involving getting a multiplicity of perspectives and as holistic and representative information as possible about the complex concept of sustainability of this industry.

The 15 qualitative semi-structured interviews were conducted in the period of January to March 2020, each lasting for 60-120 minutes. To ensure reliability of the data, all the interviews were recorded by an audio recorder, based on consent from each of the interviewees (see subchapter 3.5 for ethical issues and considerations).

3.3 Systematic literature review

A *systematic literature review* is typically conducted to identify and synthesise all relevant research on a specific topic (Ebeling & Gibbs, 2008), and was considered important to conduct as a supplement to the qualitative semi-structured interviews to obtain as holistic, complete and correct information as possible about important sustainability aspects of the macroalgae aquaculture industry. The literature review was conducted through search for relevant scientific articles and reports in the databases *Oria* and *Google Scholar*, both generally by using relevant key words, and specifically by searching for specific relevant scientific articles and reports either referred to in already identified literature or recommended by supervisors, interviewees and others. Relevant scientific literature was also found through search at websites of relevant research institutions and projects. Relevant key words used and matched together in the general search included *macroalgae, seaweed, kelp, aquaculture, cultivation, industry, business, company, sustainability, sustainable development, environmental, social, cultural, economic, governance, effects, impacts, global, Norway,* and many others.

3.4 Data analysis and development of the Wheel of Sustainability for macroalgae aquaculture

After being conducted, the recorded qualitative semi-structured interviews were transcribed through *manual* and *verbatim transcription*, which means written down without computer software and that every word mentioned were written down. These forms of transcription are very laborious and time-consuming, however, they offer the advantages that the researcher becomes thoroughly familiar with the data and that all possible analytic uses are allowed for in the later analysis, something which is a key to successful analysis of qualitative data (Fielding & Thomas, 2008).

A second key to successful analysis of qualitative data is to devise a practical system that enables systematic and thorough review and consideration of the data to identify thematically similar segments of the data, in this case sustainability aspects and related information about these, both within and between interviews, that will contribute to understanding, deeper thought and potentially new insights. The practical solution to this analytical challenge is the *coding* and subsequent retrieval of similarly coded segments together with a reference to their original location, which means interview and line number (Fielding & Thomas, 2008). In this study, the qualitative data from the semi-structured interviews and the systematic literature review, as well as the themes and indicators of the ASC-MSC Seaweed Standard, were coded according to the WOS-SA, working as such a practical system enabling systematic and thorough review and consideration of the data. This means that all mentioned and identified sustainability aspects and related information about these were grouped underneath, and thus coded according to, all relevant domains and subdomains of the WOS-SA where they fit. Some aspects did, however, only partly fit underneath some of the subdomains, and some did not fit underneath any of the subdomains at all. The grouping and coding of these aspects thus constituted the basis for proposals to modifications of existing subdomains and also to completely new subdomains, making the WOS-SA become a new model of sustainability specifically applicable to the macroalgae aquaculture industry. This process of reviewing, interpreting, considering and coding all the collected data is not elaborated any further in this thesis, however, it is important to note that the process was conducted in a systematic and thorough way, and that it constituted an essential part of the methodology. The final version of the model resulting from this process was named *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)* and is presented in subchapter 4.1 of this thesis. As several of the identified sustainability aspects of the macroalgae aquaculture industry were found to be similar to corresponding aspects of the salmon aquaculture industry, but others, including several of those that did fit underneath existing subdomains of the WOS-SA, were found to be of significant difference from corresponding aspects of the salmon aquaculture industry, there is a need for an operationalisation of what the different subdomains of the new WOS-MA actually include and mean specifically for sustainability of the macroalgae aquaculture industry. It is further a need to show the relevance of these aspects and subdomains for the Sustainable Development Goals (SDGs) which are relevant at a micro level. Based on all this, there is a need to justify all the different subdomains of the new WOS-MA. This includes both the subdomains that are the same as those of the WOS-SA, those that were modified from the WOS-SA, and those that are completely new. However, as the two latter types of subdomains are those that make the new WOS-MA specifically applicable to the macroalgae aquaculture industry, those are given the greatest focus. All this is provided in subchapter 4.2 of this thesis.

3.5 Ethical issues and considerations

Ethics is a matter of principled sensitivity to the rights of other people. Ethics say that while truth is good, respect for human dignity is better, something which means that being ethical may limit the choices one can make in the pursuit of truth. Ethical issues and considerations affect all scientific research, making researchers having to take account of effects of their actions on the people being subject of, or otherwise being participating in their research, and to act in such a way as to preserve their rights and integrity (Bulmer, 2008). One very important principle of ethical research is the principle of *informed and voluntary consent*. This means that people who are asked to participate in research must be informed about the research, what participation involves, what they are consenting to, which consequences participation may have, and that they are free to decide to participate or not based on all this information (Bulmer, 2008; NSD, 2020b). Such an informed and voluntary consent was obtained from all the interviewees participating in this study before the interviews were conducted. This was done by sending each of the potential interviewees a written information letter via email providing information as described above, and by receiving a written consent from each in return.

In Norway, all research that include collection and processing of *personal data*, which means any data relating to an identified or identifiable person, must be registered at, and approved by, the Norwegian Centre for Research Data (NSD) (NSD, 2020a). Even though the purpose of this study was not to collect any personal data about people for use in the results, the use of people as a type of data source for collecting data about sustainability aspects of the macroalgae aquaculture industry involved that personal data such as name, email, phone number, working place and working position had to be collected and stored throughout the research process to get and keep in contact with the interviewees and to keep overview of all the interviews. Therefore, the study was registered at, and become approved by, the NSD before it was initiated. To ensure *confidentiality* of these personal data, which is another important principle of ethical research (Bulmer, 2008) and part of the requirements from the NSD, the collected personal data were marked with a code in a document that was kept safe and password protected separated from other collected data. Other collected data, which means the interview recordings, were kept safe on the audio recorder separated from the personal data until the interviews were transcribed, anonymously. After the transcriptions were finished, the recordings were deleted. And when the study was ended, all types of personal data were deleted.

4 Results

This chapter presents the results of the study presented in this thesis. Essentially, these results include a new model of sustainability of the macroalgae aquaculture industry named *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)*, providing a holistic overview of important sustainability aspects, in the form of sustainability domains and subdomains, of this industry. Subchapter 4.1 presents the final version of the model. Subchapter 4.2 provides an operationalisation of what the different subdomains of this model include and mean specifically for sustainability of the macroalgae aquaculture industry, and shows their relevance for the Sustainable Development Goals (SDGs) which are relevant at a micro level. It further provides justifications of all the different subdomains of the model.

4.1 The Wheel of Sustainability for macroalgae aquaculture

This subchapter presents the final version of the WOS-MA. As the model is divided in four main sustainability domains; 'Environment', 'Economics', 'Culture' and 'Governance', these sustainability domains are presented in separate subchapters; in subchapters 4.1.1, 4.1.2, 4.1.3 and 4.1.4 respectively.

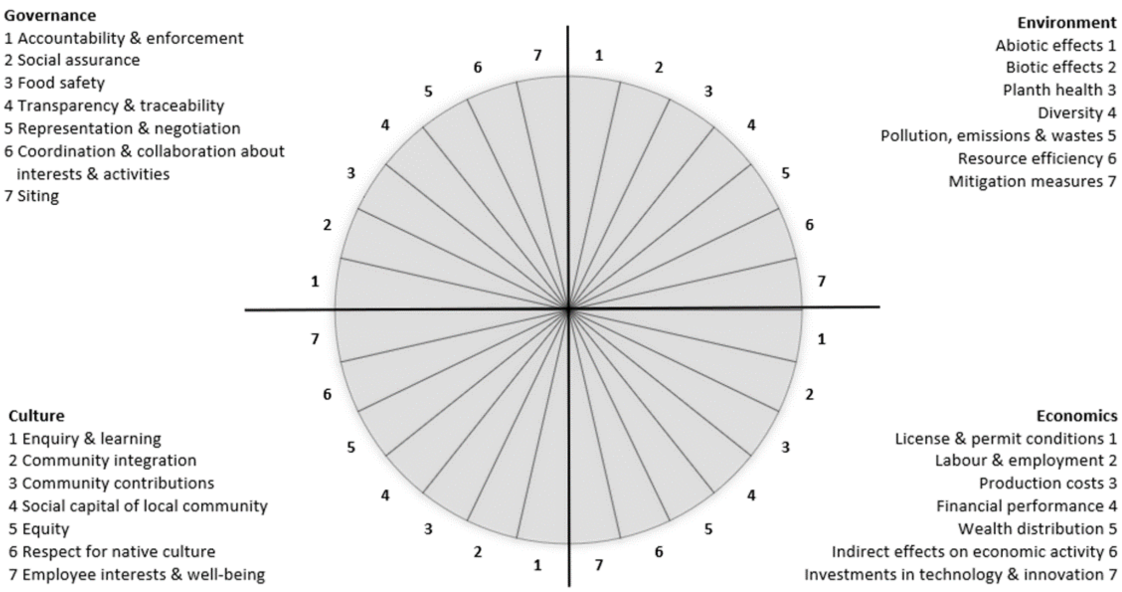

Figure 5: The Wheel of Sustainability for macroalgae aquaculture (WOS-MA).

4.1.1 Environment

Environment includes the practices, discourses and material expressions that occur across the intersection between the social and natural realms. The natural realm includes a spectrum of environmental conditions, from the untouched to the modified. This domain thus focuses on the questions of social-environmental interconnection, including human effects on and place within the environment.

Abiotic effects
This subdomain includes how effects on non-living factors of surrounding ecosystems such as lightning conditions and nutrients availability are assessed, whether such factors are continuously monitored, and whether subsequent preventive, corrective or enhancing actions are taken, dependent on whether effects are positive or negative. Surrounding ecosystems include both marine, freshwater, and terrestrial ecosystems.

Biotic effects
This subdomain includes how effects on living factors of surrounding ecosystems, including both flora and fauna, are assessed, whether such factors are continuously monitored, and whether subsequent preventive, corrective or enhancing actions are taken, dependent on whether effects are positive or negative. Surrounding ecosystems include both marine, freshwater, and terrestrial ecosystems.

Plant health
This subdomain concerns measures taken to ensure the health of the cultivated macroalgae, such as for example monitoring of biofouling organisms, diseases and pests, and subsequent preventive or corrective actions.

Diversity
This subdomain concerns how diversity, such as genetic diversity, diversity of species and diversity of products produced, is ensured throughout the industry. This may be realised through coordination and collaboration between macroalgae companies, and also between macroalgae companies and other types of companies and industries.

Pollution, emissions & wastes
This subdomain includes the assessment of environmental impacts caused by various types of pollution, including emissions and wastes, throughout the value chain, and subsequent preventive or corrective actions. The latter includes for example whether biological and non-biological waste is handled in a proper and responsible manner, through for example recycling.

Resource efficiency
This subdomain includes the assessment of efficient and sustainable utilisation of resources used throughout the value chain, such as materials and equipment, energy, facilities and infrastructure, transport and the macroalgae biomass itself. This may be realised through coordination and collaboration between macroalgae companies, and also between macroalgae companies and other types of industries.

Mitigation measures
This subdomain includes the existence of contingency plans, clean-ups, emergency plans and established routines to deal with potential mishaps.

4.1.2 Economics

Economics includes the practices, discourses and material expressions related to production, use and management of resources for production of macroalgae products. This domain contains direct measures of economic sustainability such as companies' financial return on investment, as well as economic effects on a larger scale to capture the effect of the production activity on the surrounding society.

License & permit conditions
This subdomain encompasses the conditions pertaining to how licenses and permits are obtained by the macroalgae aquaculture industry, including price, length of the permit, type of ownership, and conditions of rent, as well as conditions for production set in obtained licenses and permits.

Labour & employment
This subdomain includes economic aspects related to labour and employment, such as the relative level of salaries compared to the local, regional or national level, required skills or competence, and the availability of jobs. This refers also to the permanency vs. seasonal positions.

Production costs
This subdomain includes different aspects of production costs, such as for example costs related to labour, equipment and technology, energy, transportation, investment, capital and access to credit, and also costs related to environmental monitoring and measurements, and subsequent preventive, corrective or enhancing actions.

Financial performance
This subdomain concerns the financial performance of macroalgae aquaculture companies as measured by several possible indicators, e.g. profits, EBIT, EBIT/kg, ROI, ratio between production and loss, and difference between price and total cost (excl. salaries).

Wealth distribution
This subdomain encompasses how macroalgae companies distribute their wealth in the local, regional or national community, such as through municipal taxes.

Investments in technology & innovation
This subdomain includes investments done in research and innovation projects which may lead to development of new technology.

Indirect effects on economic activity
This subdomain encompasses investments done in public infrastructure that benefits the local community, e.g. roads, buildings, piers, slips, broadband, and housing. This subdomain also includes ripple effects such as local businesses established throughout the supply chain, e.g. infrastructure/technology producers, supply and waste management, or other businesses funded by macroalgae aquaculture money.

4.1.3 Culture

Culture is the part of the social domain that emphasises the practices, discourses and material expressions that over time express the continuities and discontinuities of social meaning of a life held in common. In other words, culture is understood as "how and why we do things around here".

Enquiry & learning
This subdomain includes engagement in research and development. This can be realised through the collaboration on behalf of macroalgae companies with the local community, schools, universities or others for research, knowledge-building and dissemination purposes.

Community integration
Community integration is about fostering a sense of identity between a company and the local community, and about taking initiatives to make the employees feel integrated in the company and creating a sense of belonging.

Community contributions
This subdomain includes how a company can be seen to contribute to the local community by e.g. donating money to the local community, e.g. to schools, sport teams, or events, or by hosting or sponsoring events.

Social capital of local community
This subdomain includes how a company attempts to sustain and promote the social capital of the local community, or in other words, the social fabric of the community, e.g. resources, relationships, social networks, and adaptive capacity. Elements of this may be expressed in the form of a social license.

Equity
This includes how a company may be seen to be upholding and improving the social structures and collective capabilities of the local community, such as gender equality, age non-discrimination, and by ensuring a generational approach. Equity emphasizes how the industry, alongside public efforts, are seen to meet the needs of groups in local communities.

Respect for native culture
This subdomain is about ensuring that a company's activities respect, value and promote the ancestral culture of the region, as many aquaculture operations are placed in areas that are claimed as traditional territories or where indigenous groups are present. This includes entering into dialogue, and establishing agreements with such groups.

Employee interests & well-being
This includes how a company ensures the well-being of the employees through initiatives such as development of expertise, career advancement opportunities, language and integration courses for foreigners, social events, etc. Procedures for conflict resolution between workers and between employer/employees are also included here.

4.1.4 Governance

Governance is the part of the social domain that emphasizes practices and meaning related to how public goods and services are provided and regulated. This refers to basic issues of social power as they pertain to the organization, authorization, legitimation and regulation of a social life held in common. It includes how the industry is regulated on a national level, but also the norms and practices initiated on a local and company level.

Accountability & enforcement
This includes knowledge of and compliance with all applicable national and local rules and regulations by a macroalgae aquaculture company, as well as enforcement and sanctions when rules and regulations are not followed. Whether or not a company has internal requirements to behaviour, and/or internal audits is also included.

Social assurance
This subdomain includes upholding the rights of employees, based on national regulations and as stated by the International Labour Organization (ILO), e.g. freedom of association, contracts, working hours, equality in hiring process, and no discrimination. Health and safety is also included here, meaning requirements of use and availability of personal protective equipment, as well as necessary training. An emphasis on upholding a safety culture through training, health plans, and a focus on potential risks in procedures and contingency plans is encompassed.

Food safety
This subdomain includes how food safety is ensured throughout the value chain. This may be done through for instances procedures, HACCP, quality systems and risk assessments.

Transparency & traceability
This subdomain includes how openness surrounding operations and decision-making processes are allowed for. This also includes the accessibility and circulation of information, both on own initiative and on request. Additional information may include e.g. degree of accessibility, available information channels, choice of language, and format. Both internal transparency within companies and institutions and external transparency towards the public, as well as record-keeping, are part of this subdomain.

Representation & negotiation
This subdomain includes the presence and influence of stakeholders facilitated through available forums where different interests and concerns can be communicated and discussed. It also contains the encouragement of participation and inclusion of stakeholders through access to information regarding operations, intentions, and plans. Resources and capacity to receive and process criticism and complaints, and evidence of how such conflicts are handled is also included.

Coordination & collaboration about interests & activities
This subdomain includes coordination with other activities in the area such as other aquaculture facilities, fisheries, recreation, and tourism, such as planning capacity and willingness to deal with conflicts from multiple uses of marine space and resources, e.g. conflicts of interest, displacement of other activities, and general loss of amenity. This includes also participatory marine spatial planning, as instigated by governments or by shared agreement. Also, collaboration about various activities and interests, both between macroalgae companies and between macroalgae companies and other industries and actors, is underneath this subdomain.

Siting

This subdomain includes how the siting process of an aquaculture location is undertaken, referring to the geographical location of the site. It encompasses how local communities and other stakeholders are consulted and heard, whether protected or vulnerable areas is considered, and whether assessment and knowledge about nearby ecosystems are included into the planning process.

4.2 Operationalisation and justification of the Wheel of Sustainability for macroalgae aquaculture

This subchapter provides an operationalisation of what the different subdomains of the WOS-MA include and mean specifically for sustainability of the macroalgae aquaculture industry, and shows their relevance for the SDGs which are relevant at a micro level. Further, it provides justifications of all the different subdomains of the model. This includes both the subdomains that are the same as those of the WOS-SA, those that were modified from the WOS-SA, and those that are completely new. However, as the two latter types of subdomains are those that make the new WOS-MA specifically applicable to the macroalgae aquaculture industry, those are given the greatest focus. This subchapter is also divided in four subchapters according to the four main sustainability domains of the model: 'Environment' (subchapter 4.2.1), 'Economics' (subchapter 4.2.2), 'Culture' (subchapter 4.2.3) and 'Governance' (subchapter 4.2.4).

4.2.1 Environment

The environmental sustainability domain is meant to acknowledge that the environment is an entity in its own regard, where humanity and our social activities and systems such as aquaculture production is both placed within the environment and may cause more or less permanent modifications of it. Focusing on the interconnections and interactions between humanity and the surrounding environment, this sustainability domain encompasses aspects related to how a social organisation within the macroalgae aquaculture industry affects the surrounding environment. This subchapter operationalises and justifies seven subdomains designed to be capturing the overall key aspects of this environmental sustainability domain, identified as important to consider in the endeavour to understand and ensure sustainability of the macroalgae aquaculture industry. It is important to point out here that this subchapter is a lot more comprehensive and detailed than the other subchapters of this chapter concerning the other sustainability domains of the WOS-MA. As described in subchapter 1.2, this is because environmental aspects were the main subject of focus among most of the interviewees, and, most importantly; because environmental sustainability was found to be the domain where the salmon and the macroalgae aquaculture industry differ most significantly, and where significant modifications of the WOS-SA had to be made to make this domain be specifically applicable to the macroalgae aquaculture industry. Thus, these aspects require more comprehensive and detailed operationalisation and justifications. This does not mean, however, that they are assigned any greater importance, weight, or value than other sustainability aspects of the WOS-MA.

Abiotic effects

Abiotic, meaning non-living, components of natural ecosystems constitute one of two main types of ecosystem components, and include physical factors such as sunlight, temperature and water flow, chemical factors such as carbon, oxygen and pH content, and physical and chemical resources such as access to water and nutrients, all making up the foundation of the habitats for the second of the two main types of ecosystem components; namely *biotic*, meaning living, components (SNL, 2020a, 2020c, 2020g). In this study, various effects of the macroalgae aquaculture industry on such abiotic components of natural ecosystems were identified as important to consider in the endeavour to understand and ensure sustainability of this industry. The subdomain of

‘Abiotic effects’ from the WOS-SA was therefore included in the WOS-MA, and all effects of the macroalgae aquaculture industry on such abiotic components of natural ecosystems are included in this subdomain. In the following, some of the most important of the hitherto known of such effects, as identified in this study, are described. These include *absorption of sunlight, absorption of* CO_2*, absorption of nutrients, absorption of pollutants, release of particulate organic matter, release of dissolved organic matter,* and *altering of hydrologic conditions*.

Absorption of sunlight
As photoautotrophic organisms, macroalgae are dependent on sunlight to live and grow. Due to this dependence on sunlight, cultivated macroalgae are attached to cultivation ropes fixed right below the sea surface, usually between one and eight metres below, to ensure optimal conditions for absorption of sunlight (Broch et al., 2016; Broch, Tiller, Skjermo, & Handå, 2017). Some of the interviewees interviewed in this study pointed out that macroalgae’s absorption of sunlight in the surface waters is an aspect that can contribute negatively to environmental sustainability of the macroalgae aquaculture industry, because this can limit the access to sunlight for other photoautotrophic organisms living in waters below. Some of these interviewees mentioned that this first and foremost concerns benthic photoautotrophic organisms such as wild macroalgae populations if the cultivated macroalgae are sited in shallow waters where such wild populations are growing (0-50 metres below the surface), while others mentioned that it concerns both benthic, and also pelagic photoautotrophic organisms such as phytoplankton. It was further pointed out that if reduced access to sunlight for such other photoautotrophic organisms, whether benthic, pelagic or both, leads to reduced primary production within an ecosystem, this may not only impact these autotrophic organisms, but also the rest of the whole food web in that ecosystem because of its fundamental dependence on autotrophic primary production. Such potential negative shading impacts on both benthic and pelagic photoautotrophic organisms and further on whole food webs are also described in the literature (Campbell et al., 2019; Hancke, Bekkby, Gilstad, Chapman, & Christie, 2018). It is important to point out here that as pelagic photoautotrophic organisms are moving with water flows, they will only experience negative shading impacts for the length of the time it takes for them to move through a cultivation site. Shading impacts on such organisms can therefore be characterised as scale dependent, meaning that impacts most likely will be minimal at small-scales for individual cultivation facilities where this transfer time will be short, but more significant at large-scales where it will be longer. However, on sites with multiple small-scale cultivation facilities, shading impacts may act cumulatively, thereby potentially being equivalently significant as at large-scales (Campbell et al., 2019). For benthic photoautotrophic organisms on the other side, shading impacts on affected organisms are occurring at a 1:1 scale, as these organisms are attached to the seabed, unable to move away from shaded areas. It is important also to point out, however, that as cultivated macroalgae typically are of microscopic dimensions when deployed into the sea during the winter, but will grow into a dense biomass during the spring, shading impacts will fluctuate with seasons and also the intensity of the cultivation (i.e. the number of individuals per surface area). The physical design of cultivation facilities is also determining for the intensity of shading impacts (Hancke et al., 2018).

Absorption of carbon dioxide (CO_2)

As photoautotrophic organisms, macroalgae release CO_2 to their surroundings through their respiration when it is dark, but are able to absorb CO_2 from their surroundings as long as they have sufficient access to sunlight. During daytime, they are therefore constantly absorbing CO_2 from their surrounding waters, and as the CO_2 concentration in the ocean waters seeks equilibrium with the CO_2 concentration in the atmosphere, this will alter the CO_2 concentration in the atmosphere as well. Macroalgae are thereby fundamentally different from fish like salmon, which are heterotrophic organisms not having this ability, and therefore only are releasing CO_2 to their surroundings through their respiration (Hancke et al., 2018; Mouritsen, 2013; SNL, 2020b, 2020e, 2020g). Almost all of the interviewees pointed out that this is a positive environmental aspect of the macroalgae aquaculture industry, because this means that cultivated macroalgae, as opposed to cultivated fish like salmon, can contribute to mitigation of negative effects of ocean acidification and climate change. These findings were also supported by literature; stating both that CO_2 absorption from macroalgae cultivation, even at large-scales, is unlikely to lead to any negative impacts due to sea waters chemistry and inherent buffering capacity (Campbell et al., 2019), and conversely, that it has the potential to contribute substantially to mitigation of negative effects of ocean acidification and climate change (Barbier et al., 2019; Campbell et al., 2019; Duarte, Wu, Xiao, Bruhn, & Krause-Jensen, 2017; Hancke et al., 2018; Krause-Jensen & Duarte, 2016; Krause-Jensen et al., 2016; Stévant et al., 2017; Wood, Capuzzo, Kirby, Mooney-McAuley, & Kerrison, 2017). However, some of these interviewees emphasised that to ensure true, long-term mitigation of such effects, it is important to understand that this must involve an actual reduction of CO_2 emissions or even a removal of CO_2 from the oceans and the atmosphere, and that this is dependent on how much CO_2 is absorbed by the macroalgae, relative to how much is leaking out again. Such leakages may occur through respiration and other natural processes during cultivation (see 'Abiotic effects' → 'Release of particulate organic matter (POM)' and 'Release of dissolved organic matter (DOM)'), which may be difficult to prevent, but may also occur through emissions connected to the utilisation of the biomass, which is more controllable. In the case of the latter, mitigation will only be temporary if the biomass is being utilised in ways that will release the absorbed CO_2 back to the environment again, such as when utilised as food and feed products which will be "burned as fuel" in human or animal respiration. However, if food and feed products, or other types of macroalgae products, will replace equivalent, emission-intensive products, and the production of such macroalgae products actually is less emission-intensive than the production of such emission-intensive products (see 'Pollution, emissions & wastes'), mitigation effects may be more permanent in terms of avoided emissions from production of more emission-intensive products. Going even further, it was mentioned among the interviewees that if we want to utilise macroalgae aquaculture not only for reduction of CO_2 emissions, but also for removal of CO_2 from the oceans and the atmosphere, the biomass must either be utilised and stored in more long-lasting products, burned with Carbon Capture and Storage (CCS)-technology, or directly deposited for sedimentation on the seabed. Concerning burning of the biomass with CCS-technology, it was emphasised, however, that utilisation of the biomass for production of various products replacing more emission-intensive products before burning the residuals, may be a more optimal utilisation of the macroalgae resource rather than burning it directly (see 'Resource efficiency'), and concerning deposition of the biomass on the seabed, it was emphasised that even though this may be a possibility, the knowledge of both possible mitigation effects and possible environmental impacts of this is still very uncertain.

Absorption of inorganic nutrients

As photoautotrophic organisms, macroalgae are not only able to absorb CO_2, but also many other inorganic compounds needed for support of their photosynthesis, respiration and growth, where the nutrients nitrogen and phosphorous are of particular importance. By constantly absorbing and thus removing such nutrients from their surrounding waters, macroalgae are thereby altering the chemistry of these waters. Here also, macroalgae are fundamentally different from heterotrophic fish like salmon, which do not have this ability of absorbing inorganic nutrients. Fish must therefore feed on, or be fed with, organic compounds initially built up by autotrophic organisms like macroalgae for use in their respiration and growth. Through feed spills and excretion, aquaculture with fish is, as opposed to aquaculture with macroalgae, thereby altering the chemistry of the surrounding waters in the form of nutrient addition (Hancke et al., 2018; Klinger & Naylor, 2012; Mouritsen, 2013; Skjermo et al., 2014; SNL, 2020b, 2020e, 2020g). Almost all of the interviewees mentioned that such absorption of nutrients by cultivated macroalgae is an important aspect for environmental sustainability of this industry. Most of them considered this exclusively as a positive aspect, because this means that cultivated macroalgae can absorb nutrients which are constantly added to the ocean waters due to feed spills, excretion and run-offs from particularly fish aquaculture and agriculture, and thereby contribute both to save valuable resources that would otherwise be lost (see 'Resource efficiency'), and to mitigate negative eutrophication impacts on marine ecosystems that may occur due to such nutrient addition. This positive bioremediation effect of macroalgae aquaculture is also described in the literature (Campbell et al., 2019; Hancke et al., 2018; Stévant et al., 2017; Wood et al., 2017). The rest of these interviewees also recognised this positive effect, however, they mentioned that this also could be a negative aspect, if nutrient absorption by cultivated macroalgae decrease the local nutrients availability to a level below that required for natural primary productivity by other autotrophic organisms in the same waters. And like with the aspect of absorption of sunlight (see 'Abiotic effects' → 'Absorption of sunlight'), they pointed out that if this leads to reduced primary production, this may have negative impacts on the whole food web in those waters due to its dependence on such primary production. Such possible negative impacts of macroalgae aquaculture are also described in the literature (Campbell et al., 2019; Hancke et al., 2018; Skjermo et al., 2014; Wood et al., 2017). Even though it was acknowledged, however, that most waters are very nutrient rich and probably highly resilient to such negative impacts, it was emphasised by several that the possibilities of both positive and negative effects nevertheless will be dependent on site-specific conditions such as particularly the extent of water flows and the supplies and exchanges of nutrients, and also the scale of cultivation facilities, including the intensity of the cultivation (i.e. the number of individuals per area).

Absorption of pollutants

Due to macroalgae's efficient ability to absorb inorganic compounds from their surrounding waters (see 'Abiotic effects' → 'Absorption of inorganic nutrients'), they are not only absorbing the nutrients they need, but also other compounds such as many types of pollutants (Barbier et al., 2019). Many of the interviewees mentioned that this may be a negative aspect of the industry, because if the cultivated macroalgae are to be used in food or feed products, this may constitute a major challenge for the safety of such products (see 'Food safety'). Two of the interviewees also pointed out, however, supported by literature (Barbier et al., 2019; Wood et al., 2017) that absorption of such compounds also can be a positive aspect, if this can be used for bioremediation purposes at polluted sites.

Release of particulate organic matter (POM)
Even though macroalgae do not release nutrients to ocean waters in the same way as heterotrophic organisms like fish do through their excrements, they are, however, regularly losing larger organic fragments; so-called *particulate organic matter (POM)*, of their tissue during growth, typically due to exposure to waves and stormy weather. Both wild macroalgae populations and cultivated macroalgae are releasing such POM, and it is a natural process that can be compared to the loss of leaves from terrestrial trees during the autumn, except that release of POM from macroalgae is occurring all year round. And like terrestrial leaves are often transported some distance away with winds and eventually deposited on the ground, POM is often transported some distance away with water flows and eventually deposited on the seabed (Campbell et al., 2019; Hancke et al., 2018). This aspect was also mentioned by many of the interviewees as important for environmental sustainability of the macroalgae aquaculture industry, in the form of both positive and negative environmental effects. On the positive side, released POM may represent a nutrient source particularly for benthic heterotrophic organisms, and it can thereby contribute to increase the nutrients availability for such organisms in otherwise nutrient-poor environments. This may in turn increase the nutrients availability and biodiversity in the whole food web in those environments (Campbell et al., 2019; Hancke et al., 2018; Skjermo et al., 2014; Wood et al., 2017). On the negative side, large-scale deposition of POM on the seabed may lead to increased anaerobic decomposition and associated depletion of oxygen and formation of toxic substances, which on the other hand may have adverse impacts on the biodiversity in the whole food web in the affected environment (Campbell et al., 2019; Hancke et al., 2018; Skjermo et al., 2014; Stévant et al., 2017; Wood et al., 2017). It was, however, pointed out by several of the interviewees that because cultivated macroalgae are harvested after only a few months growing at sea, the releases of POM from cultivation facilities are probably much smaller than those of wild macroalgae populations, at least at today's scale of cultivation. Nevertheless, as was also pointed out; this may come to have significant effects in the future if the industry develops into a large-scale industry as is desired. Whether effects of release of POM will be positive or negative were therefore characterised as dependent on the scale of cultivation facilities, including the intensity of the cultivation (i.e. the number of individuals per area), and on site-specific conditions, primarily the characteristics of water flows and seabed landscape. Another effect that was mentioned by some of the interviewees in connection to this aspect, is that released POM also may contribute to spreading of genetic material (spores), and thereby possibly to genetic pollution of wild macroalgae populations (see 'Biotic effects' → ' Spreading of non-native macroalgae species' and 'Genetic pollution of wild macroalgae populations').

Release of dissolved organic matter (DOM)
One of the interviewees further mentioned that both wild macroalgae populations and cultivated macroalgae are also constantly releasing another, smaller form of organic matter which is dissolved in the ocean water; so-called *dissolved organic matter (DOM)*. The knowledge about the effects of this is currently very limited, but as DOM seem to be a complex mixture of mainly carbohydrates containing organic carbon, this may imply that a part of the carbon absorbed by the macroalgae in the form of inorganic CO_2 (see 'Abiotic effects' → 'Absorption of CO_2'), is leaking out to the waters again during growth. However, it is also suggested that a portion of this released organic carbon may be resistant to biological breakdown, and therefore gradually can be sequestered in sediments on the seabed. In that case, the more long-term carbon effects of this DOM release may be less negative (Campbell et al., 2019; Hancke et al., 2018). Nevertheless,

according to both the interviewee and this literature, there is a need for more assessments of this aspect, and it should be considered when estimating mitigation effects of CO_2 absorption by macroalgae. Furthermore, substantial amounts of DOM in the surface waters where cultivated macroalgae are growing may also increase the absorption of sunlight in these waters, and thereby limit the access to sunlight for other photoautotrophic organisms, with similar consequences as described above (see 'Abiotic effects' → 'Absorption of sunlight') (Campbell et al., 2019; Hancke et al., 2018). This was also emphasised as an aspect that should be subject of further assessments

Altering of hydrologic conditions
Water flows and other hydrodynamics are, as implied above, influencing several abiotic effects of macroalgae aquaculture. It was mentioned by some of the interviewees that macroalgae cultivation facilities in turn also may alter hydrodynamics, with various environmental effects. Most importantly, cultivation facilities may dampen waves, water flows and water exchanges in a local area (Campbell et al., 2019; Hancke et al., 2018; Wood et al., 2017). This may contribute to coastal protection in this area, and thereby be a positive effect (Wood et al., 2017). However, it may also reduce the supplies and exchanges of oxygen, nutrients, and organisms in the same area. Particularly if these supplies and exchanges are limited in the first place, this may have negative impacts on organisms living behind or below the cultivation facilities, including both other cultivated organisms in other facilities in the area such as salmons, and wild organisms (Campbell et al., 2019; Hancke et al., 2018; Wood et al., 2017).

It should be noted here that the ASC-MSC Seaweed Standard does not address any of the aspects described above specifically, however, the standard has several indicators requiring companies to not generate negative effects on natural ecosystems in general, something which reasonably can be considered as to be including such abiotic effects.

Relevance for the SDGs and justification of modifications of the original subdomain
In this section, some of the most important of the hitherto known effects of the macroalgae aquaculture industry on abiotic components of natural ecosystems, as identified in this study, have been described. It is important to note that only abiotic effects generated by the cultivated macroalgae themselves, lying inherent in the direct interaction between the cultivated macroalgae and the surrounding natural ecosystem in the cultivation phase, have been described in this section. However, as stated initially, all types of abiotic effects of the industry are included in this subdomain. This means that other abiotic effects generated by various other elements of the industry, both in the cultivation phase and in other parts of the value chain, are also included. The reason why only abiotic effects generated by the cultivated macroalgae are described in this section, is that abiotic effects generated by other elements of the industry were considered fundamentally different from those generated by the cultivated macroalgae. Thus, these are also included, and described, in other environmental subdomains of the WOS-MA.

Regarding abiotic effects generated by the cultivated macroalgae, this operationalisation of such effects shows that macroalgae are fundamentally different from fish like salmon in several ways, and that macroalgae aquaculture consequently is affecting several abiotic components of natural ecosystems in different ways than salmon aquaculture – often in complete opposite ways. Even though macroalgae aquaculture, just like salmon aquaculture, potentially can generate several negative abiotic effects that must be minimised, this shows that macroalgae aquaculture also potentially can generate several positive abiotic effects, something which is more unlike salmon aquaculture.

By minimising such potential negative abiotic effects while also maximising potential positive abiotic effects generated by the cultivated macroalgae, macroalgae aquaculture may have a great potential to contribute substantially to several of the goals and targets of the SDGs, particularly:

- Target 2.4 about the need to ensure sustainable food production systems that, among other things, help maintain ecosystems (United Nations, 2020a).
- Targets 13.2 and 13.3, about the need to integrate climate change measures into policies, strategies and planning and improve human and institutional capacity on climate change mitigation, adaptation, impact reduction (United Nations, 2020h).
- Targets 14.1, 14.2 and 14.3, about the need to reduce effects of ocean acidification and pollution and sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts (United Nations, 2020i).
- Target 15.5 about the need to reduce the degradation of natural habitats (United Nations, 2020j).

Based on this, it was considered that the subdomain of 'Abiotic effects' in the WOS-MA should encompass both negative and positive effects on abiotic components. This is largely in opposition to the original subdomain of 'Abiotic effects' from the WOS-SA, which seem to encompass only negative effects on such components. Furthermore, it was considered that the description of what abiotic components actually mean is a bit misleading in the original subdomain from the WOS-SA, particularly with regards to the term *local habitat*. This is because even though abiotic components can be characterised as to be making up the foundation of the habitats for biotic components, habitats are nevertheless consisting of both abiotic and biotic components, where abiotic components only constitute the non-living parts of the habitats (SNL, 2020a, 2020c). Based on this, the original description of this subdomain from the WOS-SA was modified as follows:

WOS-SA:
This sub-domain includes how impacts on local habitat and water quality are assessed, and whether key environmental variables, such as terrestrial, seabed, and water resources are continuously monitored, and subsequent preventive or corrective actions.

WOS-MA:
This subdomain includes how effects on non-living factors of surrounding ecosystems such as lightning conditions and nutrients availability are assessed, whether such factors are continuously monitored, and whether subsequent preventive, corrective or enhancing actions are taken, dependent on whether effects are positive or negative. Surrounding ecosystems include both marine, freshwater, and terrestrial ecosystems.

Biotic effects

Biotic, meaning living, components of natural ecosystems constitute the second of the two main types of ecosystem components, and include living organisms acting as for example shelters, competitors for resources, predators, or foods or preys for other organisms, but also dead organisms who have been living (SNL, 2020c, 2020f). In this study, various effects of the macroalgae aquaculture industry on such biotic components of natural ecosystems were also identified as important to consider in the endeavour to understand and ensure sustainability of this industry. The subdomain of 'Biotic effects' from the WOS-SA was therefore included in the WOS-MA, and all effects on such biotic components of natural ecosystems are included in this subdomain. In the following, some of the most important of the hitherto known of such effects, as identified in this study, are described. These include *macroalgae aquaculture facilities as artificial habitats, spreading of non-native macroalgae species and strains and genetic pollution of wild macroalgae populations, spreading of other non-native species, and spreading of diseases and pests*.

Macroalgae aquaculture facilities as artificial habitats
Many of the interviewees interviewed in this study mentioned that macroalgae cultivation facilities may play a similar essential role for marine and coastal ecosystems as wild macroalgae forests do; functioning as "artificial habitats" supporting marine food webs, as long as the macroalgae grow in the ocean. By providing the same type of ecosystem services as wild macroalgae forests, cultivation facilities may attract many desired species and increase biodiversity in local areas, something which may constitute a positive effect for these areas (Campbell et al., 2019; Hancke et al., 2018; Skjermo et al., 2014; Stévant et al., 2017). However, one of the interviewees pointed out, supported by literature (Campbell et al., 2019), that there is limited evidence to suggest whether some species such as marine mammals will avoid or be attracted to cultivation facilities, and that there is a need to increase the knowledge about this to know whether cultivation facilities have positive or negative effects on such types of species. Furthermore, several of the interviewees also pointed out that as cultivated macroalgae are harvested frequently, there will frequently be a drastic removal of these artificial habitats. Most of them thought that this most likely would not result in any negative effects due to the mobility of most of the species typically attracted to cultivation facilities, making them able to move to another facility or natural macroalgae forest after harvest. However, it was emphasised that the current knowledge about this also is limited, and that it is possible that it may result in negative effects on species that have been using the cultivated macroalgae as their habitats. This is also described in literature (Campbell et al., 2019; Hancke et al., 2018; Skjermo et al., 2014; Stévant et al., 2017).

Spreading of non-native macroalgae species
Non-native species (NNS) are organisms that have been intentionally or unintentionally introduced outside their native range, usually as a consequence of human activity. Such NNS may, not always, but in many cases, have negative effects on receiving ecosystems, either by outperforming natural native species or by altering the natural native species composition within these ecosystems. This may have cascading negative effects both within the affected and other surrounding ecosystems and may thereby alter the biological balance that these ecosystems have established over thousands of years. NNS may also be associated with negative effects on cultivated organisms and/or anthropogenic structures, and thereby cause economic losses in the affected industries. NNS that threaten natural ecosystems and/or cause economic losses in this way, are referred to as *invasive non-native species (INNS)* (Barbier et al., 2019; Campbell et al., 2019; Fredriksen & Sjøtun, 2015; Stévant et al., 2017). Some of the interviewees mentioned that a potential negative aspect of the macroalgae aquaculture industry is that cultivated macroalgae potentially may act as such INNS in natural ecosystems if they are cultivated and spread in areas outside their native range. This is due to their ability to release spores, and also POM (see 'Abiotic effects' → 'Release of particulate organic matter') potentially containing spores, which are practically impossible to fence. Conversely, both are easily transported with water flows to surrounding ecosystems, where the spores may propagate and multiply. There have already been several examples of such spreading of non-native macroalgae species with subsequent negative effects due to macroalgae aquaculture globally, including in Europe (Barbier et al., 2019; Campbell et al., 2019; Fredriksen & Sjøtun, 2015; Stévant et al., 2017).

Genetic pollution of wild macroalgae populations
Related to the risk of negative effects due to cultivation of different macroalgae *species* in areas outside their native range, is the risk of *genetic pollution* of wild macroalgae populations, both due to *translocation* of different *strains*, or populations, of a specific macroalgae species, and due to production of "artificial strains" through *breeding*. Firstly, some of the interviewees mentioned that *translocation* of different strains of a specific macroalgae species for use in production of seedlings to be cultivated in areas outside their native range, which typically may be done because of their favourable phenotypic traits, can be a potential cause of such genetic pollution, due to genetic differences between different strains. The knowledge about the genetic structure of different macroalgae species and their many different strains is currently limited, however, studies indicate that there seem to be significant genetic differences between regional strains of the same species, also within Norway (Evankow et al., 2019). It was explained by these interviewees that translocation of spores or individuals originally harvested from one regional area for use in production of cultivated macroalgae in other regional areas, and potential subsequent spreading of spores from these individuals, may lead to crosses between cultivated strains and native strains living in the receiving areas. Due to such potential genetic differences between these strains even though they may be of the same species, this can thus result in a so-called *genetic pollution* of the native strains, potentially weakening these strains.

Secondly, several of the interviewees mentioned that production of "artificial strains" through *breeding* also can be a cause of such genetic pollution, of similar reasons. Most of these interviewees emphasised that breeding, with the aim of improving different phenotypic traits such as growth rate, content of one or several desirable compounds, and resistance to specific biofouling organisms, diseases and pests (see 'Plant health') of specific strains, most likely will be essential for the macroalgae aquaculture industry to succeed economically (see 'Financial performance'). However, they pointed out that such breeding, even breeding of strains originally being native to a local cultivation area, gradually may change the genetic structure of these strains in such a significant way that they eventually cannot be considered native, or even natural, anymore. In a similar way as is described in the context of translocation, such bred, "artificial strains" can then cross with natural strains living in this local area and potentially pollute and reduce their genetic diversity, potentially weakening these strains and their resilience to various environmental challenges. Such genetic pollution, due to both translocations and breeding, was thus characterised as a potential negative aspect of great importance for environmental sustainability of the macroalgae aquaculture industry. This aspect is also described as important in literature (Barbier et al., 2019; Campbell et al., 2019; Cottier-Cook et al., 2016; Fredriksen & Sjøtun, 2015; Hancke et al., 2018; Stévant et al., 2017).

Spreading of other non-native species
In addition to the risk of spreading of non-native macroalgae species and strains, it was mentioned by some of the interviewees and also described in the literature (Campbell et al., 2019; Hancke et al., 2018) that macroalgae aquaculture also potentially may contribute to spreading of other non-native and undesired species such as biofouling organisms and related, undesired organisms to natural ecosystems, with similar potential negative effects on these ecosystems as those described in the context of spreading of non-native macroalgae species above. This aspect is elaborated in the subdomain of 'Plant health'.

Spreading of diseases and pests
Closely related to the risk of spreading of other non-native and undesirable species is the risk of spreading of diseases and pests to natural ecosystems, which was also mentioned both by several of the interviewees and described in literature (Campbell et al., 2019; Hancke et al., 2018). This aspect is also elaborated in the subdomain of 'Plant health'.

All of the aspects above, except from the positive effects of 'Macroalgae aquaculture facilities as artificial habitats' are also addressed by the ASC-MSC Seaweed Standard.

Relevance for the SDGs and justification of modifications of the original subdomain
In this section, some of the most important of the hitherto known effects of the macroalgae aquaculture industry on biotic components of natural ecosystems, as identified in this study, have been described. In the same way as with abiotic effects, it is important to note that only biotic effects generated by the cultivated macroalgae themselves, lying inherent in the direct interaction between the cultivated macroalgae and the surrounding natural ecosystems in the cultivation phase, have been described in this section. However, as stated initially, all other types of biotic effects generated by various other elements of the industry are also included in this subdomain, but such other causes of biotic effects are described in other environmental subdomains of the WOS-MA. It is further important to note that as abiotic components make up the foundation of the habitats for biotic components, abiotic effects may further affect biotic components, and such effects are therefore also included in this subdomain.

Regarding biotic effects generated by the cultivated macroalgae, this operationalisation of such effects shows, in the same way as with abiotic effects, that macroalgae aquaculture potentially can generate both positive and negative effects on biotic components. Many of the negative effects are similar to negative biotic effects of salmon aquaculture, such as for example the risk of genetic pollution and spreading of undesired organisms, diseases and pests to wild populations (Klinger & Naylor, 2012). However, again, a main difference between these two types of aquaculture seems to be that macroalgae aquaculture as mentioned has the potential also to generate positive effects; in this context in the form of functioning as "artificial habitats" potentially contributing to increase biodiversity in surrounding areas. Conversely, it was not found that salmon aquaculture is able to generate any such positive biotic effects.

By minimising such potential negative biotic effects while also maximising potential positive biotic effects generated by the cultivated macroalgae, macroalgae aquaculture may have a great potential to contribute substantially to several of the goals and targets of the SDGs, particularly:
- Targets 2.4 and 2.5 about the need to ensure sustainable food production systems that, among other things, help maintain ecosystems and the genetic diversity of wild species (United Nations, 2020a).
- Targets 14.2 about the need to sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts (United Nations, 2020i).
- Targets 15.5 and 15.8 about the need to halt the loss of biodiversity, protect and prevent the extinction of threatened species, and prevent the introduction and reduce the impact of invasive alien species (United Nations, 2020j).

Based on this, it was considered that the subdomain of 'Biotic effects' in the WOS-MA should encompass both negative and positive effects on biotic components. This is largely in opposition to the subdomain of 'Biotic effects' from the WOS-SA, which seem to encompass only negative effects on such components. Furthermore, it was considered that the description of this subdomain from the WOS-SA is a bit misleading with regards to what biotic components actually mean, particularly since it seems to encompass biotic components in the form of fauna only. Based on this, the original description of this subdomain from the WOS-SA was modified in the following way:

WOS-SA:
This sub-domain includes how impacts on native species are assessed, whether biodiversity in the surrounding areas is continuously monitored, and means to ensure limited interaction with wildlife, such as measures to prevent escapes. Biodiversity includes birds, mammals, fish and bottom fauna.

WOS-MA:
This subdomain includes how effects on living factors of surrounding ecosystems, including both flora and fauna, are assessed, whether such factors are continuously monitored, and whether subsequent preventive, corrective or enhancing actions are taken, dependent on whether effects are positive or negative. Surrounding ecosystems include both marine, freshwater, and terrestrial ecosystems.

Plant health
This subdomain has been modified from the subdomain of 'Fish health & welfare' from the WOS-SA. The aspect of 'plant health', which is an aspect that in general is considered of importance for sustainability of plant biomass production, was in this study identified as an important aspect also for sustainability of the macroalgae aquaculture industry. The aspect of 'welfare' was, however, identified and considered as not to be of the same relevance for plants like macroalgae as it is for animals like fish. The subdomain of 'Fish health & welfare' from the WOS-SA was therefore included in the WOS-MA, but the title and description was modified to be excluding the aspect of 'welfare' and to be otherwise specifically applicable to the macroalgae aquaculture industry. All aspects of relevance for the health of the cultivated macroalgae and further for sustainability of the industry are thus included in this subdomain. In the following, some of the most important of the hitherto known of these, as identified in this study, are described. These include *biofouling organisms and related, undesired organisms* and *diseases and pests.*

Biofouling organisms and related, undesired organisms
One of the two main types of threats to the health of macroalgae plants and further to sustainability of the macroalgae aquaculture industry was in this study identified as to be constituted by biofouling organisms and related, undesired organisms. Many of the interviewees mentioned that biofouling organisms typically start growing on the cultivated macroalgae in the late spring and throughout the summer months, causing various negative effects on their health such as for example shading and deterioration of their matter, eventually causing them to be complete damaged at the end of the summer. As a result, the macroalgae must usually be harvested before the biomass is at its largest, and in some cases also before its chemical composition is at its optimum. Biofouling organisms were therefore mentioned by several as a great challenge for economic success of the industry (see 'Financial performance'), something which also is emphasised in the literature (Skjermo et al., 2014). Furthermore, this aspect was also described by some of the interviewees, and some of the literature (Campbell et al., 2019; Hancke et al., 2018), as a potential negative aspect also with regards to environmental sustainability, because macroalgae aquaculture facilities potentially may work as "stepping zones" for spreading of such biofouling organisms and related, undesired

organisms to other areas and natural ecosystems where they would not otherwise be able to establish, with similar potential negative effects on these areas and ecosystems as those described in the context of spreading of non-native macroalgae species above (see 'Biotic effects' → 'Spreading of non-native macroalgae species'). This is because the deterioration of the macroalgae's matter caused by such organisms contributes to release and spreading of this matter (see 'Abiotic effects' → 'Release of particulate organic matter (POM)'), and thus also to spreading of the organisms attached to it.

Diseases and pests
Closely related to the challenge of biofouling organisms and related, undesired organisms is the challenge of disease and pest outbreaks among the cultivated macroalgae caused by pathogenic microorganisms, an aspect that was also mentioned by several of the interviewees and described in the literature (Barbier et al., 2019; Campbell et al., 2019; Cottier-Cook et al., 2016; Hancke et al., 2018). It was emphasised that there have not been any problems with disease and pest outbreaks within the Norwegian industry yet. However, it was nevertheless mentioned by several as a potential future challenge because the risk of such disease and pest outbreaks is typically intensified in large and intensive monocultures characterised by reduced genetic diversity due to selection and breeding of certain genetics producing certain favourable phenotypic traits, something which typically may be desired for the Norwegian macroalgae aquaculture industry to succeed economically (see 'Financial performance'). This is already seen in the macroalgae aquaculture industry in several countries in Asia, were large parts of the production are lost due to such disease and pest outbreaks (Cottier-Cook et al., 2016). In the same way as the aspect of biofouling organisms and related, undesired organisms, this aspect was thus characterised as a potential future challenge for economic success of the industry (see 'Financial performance'). Disease and pest outbreaks were also described by some, supported by literature (Campbell et al., 2019; Hancke et al., 2018), as a potential negative aspect also with regards to environmental sustainability, because there may be a risk that such diseases and pests may spread to natural populations, including both natural populations of macroalgae, and of other species.

Relevance for the SDGs and justification of modifications of the original subdomain
As these aspects constitute potential negative challenges for biotic components of surrounding natural ecosystems, addressing these aspects can thus minimise these challenges and constitute substantial contributions to the same goals and targets of the SDGs as described in the subdomain of 'Biotic effects'.

Based on the operationalisation and considerations of this aspect of 'plant health' and its relevance for sustainability of the macroalgae aquaculture industry as described above, the subdomain of 'Fish health & welfare' from the WOS-SA was modified in the following way to be specifically applicable to the macroalgae aquaculture industry in the WOS-MA:

WOS-SA:
This concerns measures taken by the aquaculture company to ensure the health and welfare of salmon and cleaner fish. This subdomain includes monitoring of diseases and parasites, vaccines, therapeutic treatments, extent of mortalities, etc.

WOS-MA:
This subdomain concerns measures taken to ensure the health of the cultivated macroalgae, such as for example monitoring of biofouling organisms, diseases and pests, and subsequent preventive or corrective actions.

Diversity

'Diversity' is a new subdomain created for inclusion in the new WOS-MA. *Diversity* of different dimensions of a system is regarded as a key feature contributing to high *resilience* of the system, that is; the system's ability to handle various challenges and changing conditions, something which in turn is regarded as essential with regards to the sustainability of the system (Folke, 2016). Diversity of different dimensions of the macroalgae aquaculture industry was in this study identified as important also for sustainability of this industry, and such diversity dimensions are therefore included in this new subdomain. In the following, some of the most important of these, as identified in this study, are described. This includes *genetic diversity of species and strains, diversity of species,* and *diversity of products and production forms*.

Genetic diversity of species and strains

Firstly, it was mentioned by some of the interviewees that ensuring high genetic diversity of cultivated macroalgae species and strains is important. This was mentioned particularly as important to prevent pollution and reduction of the genetic diversity, and thus reduction of the resilience, of wild macroalgae populations that may result from crosses between cultivated and wild populations (see 'Biotic effects' → 'Genetic pollution of wild macroalgae populations'), but also as important to ensure high resilience of cultivated populations to biofouling organisms and related, undesired species, and to pathogenic microorganisms causing diseases and pests (see 'Plant health'). The latter is regarded as important to minimise losses of the cultivated biomass, which is of importance for economic success of the industry (see 'Financial performance'), but also to prevent spreading of such organisms to wild populations, which is of importance for environmental sustainability (Campbell et al., 2019; Cottier-Cook et al., 2016).

Diversity of species

It was also mentioned by a few that cultivation of a diversity of macroalgae species (as long as they are native; see 'Biotic effects' → 'Spreading of non-native macroalgae species'), also may be important to contribute to ensure high resilience to and prevent spreading of various undesired organisms. One of these interviewees mentioned in this context that it could be important for the industry to try to aim for a kind of *crop rotation system* as is being practiced in some parts of terrestrial agriculture, where a diversity of species are cultivated alternately in the same area to improve soil health, nutrient availability, and the resilience of the crops to diseases, pests and also to extreme weather events (FAO, 2018, 2019). The interviewee explained that such a crop rotation system not necessarily may involve only cultivation of a diversity of macroalgae species, but possibly also cultivation of a diversity of other species together with the macroalgae. This is typically what is done in so-called *integrated multi-trophic aquaculture (IMTA)*, where macroalgae and potentially also other low-trophic, filtering organisms such as mussels, are placed alongside salmon in integrated aquaculture facilities (Broch et al., 2013; Fossberg et al., 2018; Wang, Olsen, Reitan, & Olsen, 2012). The interviewee explained that such cultivation and integration of different types of species potentially not only may involve that the macroalgae can absorb inorganic nutrients released to the waters due to feed loss and excretion from the fish and with this contribute to prevent negative eutrophication effects and save valuable resources that otherwise would be lost (see 'Abiotic effects' → 'Absorption of inorganic nutrients' and 'Resource efficiency'), but also that the filtering organisms may contribute to prevent various undesired organisms from affecting the macroalgae. It was further explained that aiming for such cultivation and integration of a diversity of macroalgae species and other species does not necessarily mean that each producer should aim to do this in each facility, but that the industry as a whole should aim for this. This may thus require a macroalgae company to coordinate its production with both other macroalgae companies, but also other types of aquaculture companies cultivating, or farming, other types of organisms (see 'Coordination and collaboration about interests & activities').

Diversity of products and production forms
Several of the interviewees, and literature (Skjermo et al., 2014; Stevant et al., 2017), also mentioned that production of a diversity of products is regarded as important for economic success of the macroalgae aquaculture industry as a whole (see 'Financial performance'). Cultivation of a diversity of macroalgae species, and also as complete utilisation of the macroalgae biomass as possible (see 'Resource efficiency' → 'Complete utilisation of the macroalgae biomass') may be an important part of this because different species and different types of components of the biomass may be best suited for production of different types of products (Skjermo et al., 2014; Stevant et al., 2017).

As can be regarded as related to this, the interviewee who mentioned the importance of aiming for a kind of crop rotation system as described above, further mentioned that it would be important to not only try to aim for cultivation of a diversity of species, but, in connection with this, also to try to aim for development of different types of macroalgae companies producing a diversity of different types of products with different types of production forms. This was explained to involve for example that both very small-scale companies producing macroalgae biomass for production of niche products, and more large-scale companies producing macroalgae biomass for production of other types of products, should be a part of the industry. In such a situation, it was explained that placing small-scale companies at locations along the coast, while placing large-scale facilities with monocultures more off-shore (see 'Coordination & collaboration about interests and activities') probably could be a solution to better prevent and handle some of the potential negative environmental effects of the industry, such as negative effects connected to various undesired organisms.

Relevance for the SDGs and justification of inclusion of a new subdomain
Regarding assurance of diversity to ensure environmental sustainability, this is also a subject of focus of the SDGs, which explicitly address this need in their targets, most importantly:
- Target 2.5 about the need to maintain the genetic diversity of seeds, cultivated plants, farmed animals, and their related wild species (United Nations, 2020a).
- Targets 15.5 and 15.9 about the need to halt the loss of biodiversity and integrate ecosystem and biodiversity values into both national and local planning and development processes (United Nations, 2020j).

Regarding assurance of diversity to ensure economic sustainability, this is also addressed by the SDGs; in target 8.2 about the need to achieve higher levels of economic productivity through, among other things, diversification (United Nations, 2020e).

Based on this, it was considered important to include a subdomain of 'Diversity' in the WOS-MA. As this was not found to be existing in the original WOS-SA, a new subdomain was therefore created for inclusion in the WOS-MA:

WOS-MA:
This subdomain concerns how diversity, such as genetic diversity, diversity of species and diversity of products produced, is ensured throughout the industry. This may be realised through coordination and collaboration between macroalgae companies, and also between macroalgae companies and other types of companies and industries.

Pollution, emissions & wastes
This subdomain is a composition, with modifications, of the two subdomains 'Emission & waste', and 'Energy consumption & GHG emissions' from the WOS-SA. *Pollution* is a comprehensive term; involving the addition of solid substances, liquids or gases to air, water or soil (thus being including the terms *emissions* and *wastes* also), noise, shaking, light and other types of radiation, and also effects on temperature, causing trouble or harm to the health or well-being of various biotic components, including humans, or damage to various abiotic components (KLD, 1983; SNL, 2020d) (see 'Abiotic effects' and 'Biotic effects'). Pollution can thus be considered to be, by definition, an important aspect with regards to sustainability, and it was in this study identified as important also with regards to sustainability of the macroalgae aquaculture industry. Pollution in general was mentioned as important, but several of the interviewees also mentioned several concrete types of pollution in this context, which included *addition of artificial materials*, *addition of harmful chemicals and related substances,* and *addition of GHG emissions. Noise, light and odour* were additionally mentioned in the literature.

Addition of artificial materials
First, it was mentioned by some of the interviewees and described in the literature (Campbell et al., 2019; Hancke et al., 2018) that addition of different types of artificial materials, or parts of such, from macroalgae aquaculture facilities is an important type of pollution that should be avoided. Macroalgae cultivation facilities are typically comprised of different floats, ropes and moorings, and many other different kinds of materials and equipment are also being used in the handling of the macroalgae and in operation of the facilities. Loss of such materials, either whole materials such as ropes, or parts of materials such as small parts of ropes, microplastics, etc., may contribute to various negative effects for the surrounding ecosystems and areas such as for example entanglements and accumulation of microplastics in different marine species, which often results in death (Campbell et al., 2019; Hancke et al., 2018). It was further mentioned by several of the interviewees that abandoning of whole facilities, for example due to bankruptcy, also can be regarded as such a type of pollution that should be avoided. Both of these aspects are also addressed by the ASC-MSC Seaweed Standard.

Addition of harmful chemicals and related substances
In addition to artificial materials, it was further mentioned by some of the interviewees that addition of harmful chemicals and related substances to surrounding ecosystems and areas from activities in all parts of the value chain also should be avoided. It was pointed out that there is no point of using harmful pesticides and related substances in the macroalgae aquaculture industry like there is in terrestrial agriculture because the macroalgae are cultivated in open waters, and that there in general seems to be no use of any kinds of harmful chemicals and related substances in this industry at current times. Nevertheless, they emphasised the importance of keeping it like this. This is also emphasised in the literature (Barbier et al., 2019; Cottier-Cook et al., 2016), and addressed by the ASC-MSC Seaweed Standard.

Addition of GHG emissions
Among the concrete types of pollution, addition of GHG emissions was the most frequently mentioned among the interviewees in this study, where most of them mentioned this aspect in connection to the use of energy and/or transportation. Regarding GHG emissions due to the use of energy, it was mentioned that this may occur in several parts of the value chain, however, most of the interviewees pointed out that drying of the macroalgae biomass in the processing phase is the most important part due

to the very large use of energy in this process. This is also found in the literature (Oirschot et al., 2017; Philis, Gracey, Fet, Gansel, & Rebours, 2018). Different kinds of measures to reduce the amount of energy used, and the GHG emissions resulting from such use of energy for example by using renewable energy sources, were thus emphasised as important.

Regarding GHG emissions due to transport, it was, here too, pointed out that this may occur both in, and also between, several parts of the value chain, but GHG emissions from transport in the form of boats, typically being used to transport the macroalgae biomass from the sea to land after harvest, was the most frequently mentioned. Due to this, it was mentioned as important to initiate measures to try to reduce the amount of transport required, and the GHG emissions resulting from such use of transport, for example by using fuel from renewable sources.

Addition of noise, light and odour
In addition to the above-mentioned aspects, addition of noise, light and odour due to activities in the value chain were also addressed by the literature (Campbell et al., 2019) and the ASC-MSC Standard as concrete pollution aspects that should be avoided.

Relevance for the SDGs and justification of modifications of the original subdomain
Avoiding and reducing different kinds of pollution to ensure environmental sustainability is also an important subject of focus of the SDGs, which explicitly address this in several of their targets, most importantly:
- Target 3.9 about the need to reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution (United Nations, 2020b).
- Target 6.3 about the need to improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally (United Nations, 2020c).
- Target 7.2 about the need to increase the share of renewable energy in the global energy mix (United Nations, 2020d).
- Target 9.4 about the need to upgrade infrastructure and retrofit industries to make them sustainable, with greater adoption of clean and environmentally sound technologies and industrial processes, among other things (United Nations, 2020f).
- Targets 12.4 and 12.5 about the need to achieve environmentally sound management of chemicals and wastes throughout their life cycle, and reduce their generation and release to air, water and soil to minimize their impacts on human health and the environment (United Nations, 2020g).
- Target 14.1 about the need to prevent and reduce marine pollution of all kinds, including marine debris and nutrient pollution (United Nations, 2020i).

In the WOS-SA, the subdomain of 'Emission & waste' is described as being addressing pollution and related environmental impacts. Thus, based on all of the above, it was considered important to include this subdomain in the WOS-MA. However, the title of this subdomain in the WOS-SA is formulated as being addressing only some types of pollution (emissions and wastes), and as pollution in general was identified as important for sustainability of the macroalgae aquaculture industry in this study, it was considered necessary to extend this title from 'Emission & waste' in the WOS-SA to 'Pollution, emissions & wastes' in the WOS-MA. Furthermore, it was considered convenient to include the aspect of GHG emissions from the subdomain of 'Energy consumption & GHG emissions' from the WOS-SA into this subdomain of 'Pollution, emissions & wastes' in the

WOS-MA, to include all aspects of pollution in one subdomain (and to leave the aspect of energy efficiency for the subdomain of 'Resource efficiency', which is described below). Based on this, the original description of the subdomain of 'Emission & waste' from the WOS-SA was modified in the following way:

WOS-SA:
This includes the assessment of environmental impacts caused by production waste and pollution through mortality, feed, the use of chemicals, etc. Further, it relates to what extent biological and non-biological waste is handled in a proper and responsible manner, through for instance recycling.

WOS-MA:
This subdomain includes the assessment of environmental impacts caused by various types of pollution, including emissions and wastes, throughout the value chain, and subsequent preventive or corrective actions. The latter includes for example whether biological and non-biological waste is handled in a proper and responsible manner, through for example recycling.

Resource efficiency
This subdomain has been modified from the subdomain of 'Energy consumption & GHG emissions' from the WOS-SA. In the WOS-SA, this subdomain includes the assessment of efficient and sustainable use of energy, and continuous monitoring of GHG emissions throughout the value chain. This was identified in this study as important also for sustainability of the macroalgae aquaculture industry, however, it was found that not only efficient and sustainable use of energy, but of various resources in general, is important with regards to this, as it was mentioned by some of the interviewees that ensuring such efficient and sustainable use of energy and other resources will have positive effects on both economic sustainability, in the form of reduced production costs (see 'Production costs'), and on environmental sustainability, in the form of saved resources and reduced pollution from the use of such resources (see 'Pollution, emissions & wastes'). In this context, resource efficiency through *coordination and collaboration between companies, and also industries*, *about the use, and reuse, of different resources*, and also resource efficiency through *complete utilisation of the macroalgae biomass* was identified as some of the most important.

Materials and equipment
Firstly, it was mentioned by some of the interviewees that companies of the macroalgae aquaculture industry should aim to reuse various materials and equipment, instead of continuously buy and use new. In this context, it was mentioned by one of the interviewees that companies of this industry may have a great opportunity to reuse various materials and equipment that not only previously have been used by themselves, but also by other industries, such as the salmon aquaculture industry. It was explained that this is so because the salmon aquaculture industry is required to exchange materials regularly, typically due to security reasons. It was emphasised that security, for example in the form of ensuring that materials and equipment are fit for purpose (see 'Mitigation measures') is important also in the macroalgae aquaculture industry, however, it was explained that macroalgae cultivation facilities, at least at current times, typically are of less weight and complexity than salmon cultivation facilities, and therefore, that the standards of these materials currently are sufficient for use in macroalgae aquaculture. This should anyhow be checked and approved before use.

Energy
A related aspect was also mentioned regarding the use of energy. To utilise energy in the most efficient and sustainable way possible, it was mentioned by some of the interviewees that companies of the macroalgae aquaculture industry should aim to use as little and efficient energy-demanding processes as possible (particularly with regards to drying) (see 'Investments in technology & innovation'). However, it was mentioned that it also may be possible to coordinate such energy-demanding processes with activities of other industries generating surplus heat and energy, and use this heat and energy as alternative energy sources. This thus involves utilisation of a resource that otherwise would have been lost, something which reasonably can be characterised as sustainable. This possibility has already been investigated, with promising results (PROMAC, 2020; Stévant et al., 2015).

Facilities and infrastructure
Going even further, it was mentioned by several of the interviewees that macroalgae companies should aim to coordinate and collaborate, both with each other and also with other types of industries, about the use, and reuse, of whole facilities and infrastructures, to use these, and related resources, in the most efficient and sustainable way possible. For example, as there might be way too expensive, and inefficient, for one macroalgae company to invest in and use a whole processing facility only for its own production (see 'Investments in technology & innovation' and 'Production costs'), it was mentioned that several companies within a certain area could maybe invest in and use such a facility together. Another possibility that was mentioned is to coordinate and collaborate with other industries about using the same processing facilities, preferably with other seasonal industries such as for example fisheries and the crab industry, which use different kinds of processing facilities at certain times of the year. By using such facilities at times of the year when they are not in use by such other industries (if possible), this will also, in a kind of way, involve utilisation of a resource that otherwise would have been "lost".

Regarding the cultivation phase, *integrated multi-trophic aquaculture (IMTA)*, where macroalgae and potentially also other low-trophic, filtering organisms such as mussels, are placed alongside salmon in integrated aquaculture facilities, was mentioned by some of the interviewees as another possibility for resource efficiency. As macroalgae are able to absorb inorganic nutrients released to the waters from feed loss and excretion from the fish (see 'Abiotic effects' → 'Absorption of inorganic nutrients'), IMTA may not only be an opportunity to prevent negative eutrophication effects of nutrients release from the fish, but also to save valuable resources that otherwise would have been lost (Broch et al., 2013; Fossberg et al., 2018; Wang et al., 2012), and to possibly contribute to resolve conflicts about the areas of the coastal zone by using these areas more efficiently (Hancke et al., 2018; Stévant et al., 2017) (see 'Collaboration and coordination of interests and activities'). However, it was pointed out by most of these interviewees that there has been found to be some challenges related to both the practical operation and the potential benefits of IMTA, and that both this practical operation and these potential benefits may be more optimised if macroalgae and salmon aquaculture facilities are placed with some more distance between each other within a certain area, instead of being completely integrated. Going even further, it was also mentioned by some of the interviewees that there might be a possibility to connect macroalgae aquaculture to oil platforms and/or windmill facilities off-shore, and then share the same infrastructure, equipment, energy, transport, and many other resources. It was emphasised, however, that this requires significant technical innovation (see 'Investments in technology & innovation') and may not be possible until several years in the future.

Transport
Aiming for as efficient use of transport as possible was also mentioned as important.

Complete utilisation of the macroalgae biomass
Lastly, it was pointed out by several of the interviewees that as complete utilisation of the macroalgae biomass itself as possible, meaning extracting and utilising as many components of it as possible for use in many different products (see 'Diversity'), and thus producing more with the help of less and minimising residues and wastes of the biomass (see 'Pollution, emissions & wastes), also is important with regards to both economic and environmental sustainability. To be able to do this, it was, however, emphasised that development of proper processing technologies and facilities is needed (see 'Investments in innovation and technology'). It was also emphasised by one that the benefits of such complete utilisation of the biomass must be seen in relation to use of other resources in the production – it might for example not be an environmentally friendly solution to utilise the biomass completely if the processing technologies required for doing this are more emissions-intensive than those of the production of corresponding products based on other raw materials (see 'Pollution, emissions & wastes).

Relevance for the SDGs and justification of modifications of the original subdomain
The importance of aiming for resource efficiency to ensure environmental sustainability is also addressed by the SDGs through several of their targets, most importantly:
- Target 7.3 about the need to double the global rate of improvement in energy efficiency (United Nations, 2020d).
- Target 8.4 about the need to improve global resource efficiency in consumption and production, among other things (United Nations, 2020e).
- Target 9.4 about the need to upgrade infrastructure and retrofit industries to make them sustainable, with, among other things, increased resource-use efficiency (United Nations, 2020f).
- Targets 12.2 and 12.5, about the need to achieve the sustainable management and efficient use of natural resources, and substantially reduce waste generation through prevention, reduction, recycling and reuse (United Nations, 2020g).

Based on all this, the title and description of the subdomain of 'Energy consumption & GHG emissions' in the WOS-SA were (after including the aspect of GHG emissions primarily in the subdomain of 'Pollution, emissions & wastes') modified as follows:

WOS-SA:
Energy Consumption & GHG Emissions
This includes assessment of efficient and sustainable use of energy, and continuous monitoring of emissions throughout the production chain.

WOS-MA:
Resource efficiency
This subdomain includes the assessment of efficient and sustainable utilisation of resources used throughout the value chain, such as materials and equipment, energy, facilities and infrastructure, transport and the macroalgae biomass itself. This may be realised through coordination and collaboration between macroalgae companies, and also between macroalgae companies and other types of industries.

Mitigation measures
In the WOS-SA, the subdomain of 'Mitigation measures' emphasises the importance of the existence of contingency plans, emergency plans and established routines for clean-ups and other actions to deal with different kinds of potential mishaps and emergency events within the salmon aquaculture industry that may adversely affect the fish or the environment, such as for example bad weather events or even natural disasters, fires, explosions, spills and leakages, failures of materials and equipment, fish escapes, disease outbreaks, mass mortalities, disruption to key services such as water, energy, refrigeration processes and transport, malicious contamination or sabotage, and many other things (Amundsen & Osmundsen, 2018; Osmundsen et al., 2020).

In addition to many relevant preventive and corrective actions that were mentioned specifically connected to each of the different sustainability aspects described above, several of the interviewees interviewed in this study mentioned the importance of mitigation measures in the form of ensuring that materials and equipment are fit for purpose (for example able to withstand bad weather events) and that they are monitored, and to have routines for clean-ups, including clean-ups of whole facilities for example in the case of bankruptcy, to prevent different kinds of adverse effects of the macroalgae aquaculture industry on the environment. Even though few other types of mitigation measures connected to other types of potential mishaps and emergency events within this industry were explicitly mentioned by the interviewees, it was nevertheless considered that, except from some "fish-specific" mishaps and emergency events such as for example fish escapes and mass mortalities due to for example algal blooms, a lot of other types of mishaps and emergency events as are included in the subdomain of 'Mitigation measures' from the WOS-SA are also relevant for the macroalgae aquaculture industry, as well as many other industries, such as for example fires, spills and leakages, disruption to key services, and many other things. Based on this, it was considered important to include this subdomain also in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Feed
Regarding the subdomain of 'Feed' in the WOS-SA, this subdomain was, of the obvious reason that macroalgae are plants not requiring any feed, not included in the WOS-MA.

4.2.2 Economics

The economic sustainability domain encompasses both economic aspects related directly to companies such as for example aspects related to their financial profitability, but also aspects related to economic effects of companies and industries on the broader society. This subchapter operationalises and justifies seven subdomains designed to be capturing the overall key aspects of this economic sustainability domain, identified as important to understand and ensure sustainability of the macroalgae aquaculture industry. It is important to point out here that this subchapter is much less comprehensive and detailed than the previous subchapter concerning environmental sustainability in the WOS-MA. This is mainly because most economic aspects, as opposed to many environmental aspects, were found to be of a largely general character being of similar importance regardless of aquaculture type (and in many cases even regardless of industry type), and are described in a general way in the WOS-SA. Thus, almost no modifications of the WOS-SA were found to be required to make this domain be specifically applicable to the macroalgae aquaculture industry. This does not mean, however, that these aspects are assigned any less importance, weight, or value than environmental aspects of WOS-MA.

License & permit conditions

In the WOS-SA, the subdomain of 'License & permit conditions' encompasses conditions pertaining to how licenses and permits are obtained by the salmon aquaculture industry, including for example price and conditions for production set in obtained licenses and permits. According to the Norwegian Aquaculture Act, all who want to start with any form of commercial aquaculture production in Norway, whether with fish, crustaceans, macroalgae or other types of marine organisms, must be granted a permit from the public authorities to be allowed to do this. Such a granted permit gives right to commercial aquaculture production of specific species at defined geographical areas, but a number of different types of conditions for different types of aspects related to such production can be set in the permit (NFD, 2005). This indicates that this aspect is just as relevant for the macroalgae aquaculture industry as for the salmon aquaculture industry.

Some of the interviewees referred to this fact that a permit must be granted to be allowed to start with aquaculture with macroalgae, and that this aspect may be of economic importance for macroalgae companies, particularly in the form of direct costs related to how permits are obtained. But it was also pointed out that several of the costs and conditions that are connected to such permits typically are set to ensure other sustainability aspects of the industry, particularly environmental sustainability aspects, which means that this aspect is of importance also for such other sustainability aspects. An example of this that was mentioned by several of the interviewees is a recently introduced requirement of a deposit fee from all macroalgae producers to ensure availability of economic means to clean up macroalgae aquaculture facilities and thus prevent pollution in the case of bankruptcy, or other reasons for permanent shutdown of facilities (see 'Pollution, emissions & wastes') (Landmark & Bryde, 2017; NFD, 2004). It was emphasised that such costs and conditions are important to ensure such other sustainability aspects of the industry, but it was pointed out that it is important also to ensure that they are not so economically expensive that no small-scale companies are able to enter the industry.

Based on this, the subdomain of 'License & permit conditions' from the WOS-SA was considered important to include in the WOS-MA, and that there was no need for any modifications of it to make it be applicable to the macroalgae aquaculture industry.

Labour & employment

In the WOS-SA, the subdomain of 'Labour & employment' includes different aspects related to economic compensation for labour such as the level of salaries, overtime and type of employment, but also other types of aspects related to labour and employment, such as the availability of jobs and the required skills or competences. Such aspects can reasonably be considered important for all types of employees, and thus, they can further be considered important not only in the salmon aquaculture industry, but in all types of companies and industries requiring any form of labour and employment, including also the macroalgae aquaculture industry.

This was considered to be supported by several of the interviewees interviewed in this study who mentioned several of such labour and employment aspects as important for the macroalgae aquaculture industry. *Creation of available jobs* was the main aspect of focus, but some did also mention *requirement of relevant skills and competences*, and a few did, in the context of ensuring basic rights of employment (see 'Social assurance'), additionally mention that *ensuring proper salary levels and conditions* also is important. Regarding the former, it is important to elaborate that as cultivation of macroalgae, just like farming of salmon, has to take place along the coast, it was emphasised by many that not only the creation of available jobs, but the creation of available jobs in districts and local communities along the coast functioning as a source of income for people living in such places, is a particularly important potential positive labour and employment aspect of this industry, because this will be a strong contributor to make people able to live in such places instead of being forced to move to centralised places to have such an income. In this context, it was emphasised by one of the interviewees that it is important to try to keep not only the cultivation of the macroalgae, but also other parts of the value chain such as for example processing activities, and also the administration and ownership of the different companies in these different parts of the value chain, within such districts and local communities instead of centralising and even internationalising as much as possible – something which has largely become the case in the salmon aquaculture industry. This was explained to be because, among other things, this will contribute to ensure a greater availability of a greater diversity of jobs requiring a greater diversity of skills and competences in such places, something which will make even more people, and also more people with, exactly, different types of skills and competences able to live here. This may mean a lot for each person, but is also something that may constitute important resources for communities as wholes. Thus, this may also be a contribution to the social capital of such communities (see 'Social capital of local community').

It may also be important to elaborate that some of the interviewees mentioned that it is important that people working in the macroalgae aquaculture industry actually have specific, knowledge-based skills and competences relevant for tasks that are specific for this industry, such as tasks related to the cultivation of the macroalgae, but that there currently are very few possibilities for education and courses targeting exactly this. It was therefore emphasised that this should start coming in universities and schools.

Based on all of the above, it was considered important to include the subdomain of 'Labour & employment', including all its relevant aspects, from the WOS-SA in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Production costs

The aspect of 'Production costs' which is included as a subdomain in the WOS-SA can also reasonably be considered important for economic sustainability of not only companies of the salmon aquaculture industry, but of all types of companies and industries, in the sense that all types of companies and industries have some kind of production costs related to their business, and if such costs are (too) high (relative to incomes), they may threaten the financial profitability (see 'Financial performance'), and thus, the survival and continued existence of these companies and industries.

Such production costs were mentioned by several of the interviewees in this study as important also for the macroalgae aquaculture industry, and it is important to elaborate here that it was mentioned by several as particularly important for the Norwegian macroalgae aquaculture industry. This was explained to be because Norway is a high-cost country compared to most other countries, something which make such production costs particularly high in Norway compared to those in most other countries. This includes also so-called regular costs, that is; costs that are of the same size (almost) regardless of the size of a production, such as for example renting of storage rooms. This means that such costs must either be minimised, for example through collaboration about use of such resources (see 'Resource efficiency') and/or that the production, and/or the prize of the produced products, need to be of a certain, relatively large size for the incomes to become larger than the costs. Examples of costs that were mentioned were costs related to *investments in, renting of and/or use of facilities, storage rooms, materials, equipment, technology, energy, transportation,* and, most frequently mentioned; *costs in the form of salaries to employees* (see 'Labour and employment').

Justification of modifications of the original subdomain

Based on this, it was considered important to include the subdomain of 'Production costs' from the WOS-SA in the WOS-MA. However, as many of the examples of such costs in the original description of this subdomain from the WOS-SA are specifically applicable to the salmon aquaculture industry and not relevant for the macroalgae aquaculture industry, some modifications of these examples were made to make the subdomain be applicable to the macroalgae aquaculture industry. These can be seen in the following:

WOS-SA:

This subdomain includes indicators that refer to different aspects of production costs, such as feed, transportation, slaughtering, labour, investment, capital and access to credit, but also environmental monitoring and measurements. It refers to the cost of treatment of diseases and parasites, such as vaccines, therapeutic treatments, non-medical treatments and veterinary services.

WOS-MA:

This subdomain includes different aspects of production costs, such as for example costs related to labour, equipment and technology, energy, transportation, investment, capital and access to credit, and also costs related to environmental monitoring and measurements, and subsequent preventive, corrective or enhancing actions.

Financial performance
Closely related to the aspect of 'Production costs' is the aspect of 'Financial performance'. This aspect can also reasonably be considered important for economic sustainability of not only companies of the salmon aquaculture industry, but of all types of companies and industries, in the sense that all types of companies and industries need to achieve positive financial performance, typically expressed as financial profitability meaning generation of higher incomes than costs, in order to survive and continue to exist.

Such financial profitability was mentioned explicitly by almost all of the interviewees in this study as important also for the macroalgae aquaculture industry. A frequently mentioned statement among the interviewees describing quite directly the importance of this aspect was: "Without financial profitability, there will simply be no macroalgae aquaculture industry". It was further mentioned that this is currently a main aspect of focus for the Norwegian macroalgae aquaculture industry, because most of the companies of this young and emerging industry are in fact currently not financially profitable yet.

A number of aspects of importance for the achievement of financial profitability of these companies and this industry were described, both by the interviewees and the literature. Regarding the seedling, cultivation and harvest phase, some of the most frequently described of such aspects were the need to *cultivate a diversity of* species (as long as native; see 'Biotic effects' → 'Spreading of non-native macroalgae species') *that can be cultivated for extraction of a diversity of components for use in a diversity of products* (see 'Diversity'), the need to *cultivate strains of high quality that maximises gains and minimise losses*, that is; strains that have a high content of desired components, are fast-growing and high-yielding, and have a high resistance to biofouling organisms, diseases and pests (see 'Plant health') (where much of this typically may be realised through breeding, however, for potential negative effects related to breeding; see 'Biotic effects' → 'Genetic pollution of wild macroalgae populations'), the need for *large cultivation areas with optimal cultivation conditions* (see 'Siting'), and the need for *automated and efficient cultivation, deployment and harvest technologies and practices* (see 'Investments in technology & innovation' and 'Enquiry & learning'). Regarding the pre-processing and processing phase, some of the most frequently described of such aspects were the need for *automated and efficient pre-processing and processing technologies and practices* (see 'Investments in technology & innovation' and 'Enquiry & learning'), which also enables as *complete utilisation of all components of the biomass as possible* for use in a diversity of products (see 'Resource efficiency' → Complete utilisation of the biomass'). Regarding the market phase, some of the most frequently described of such aspects were the need to *inform consumers and markets,* but at the same time *investigate and increase knowledge of what types of products the consumers and markets are actually needing and demanding*, and to aim for *optimal combinations of high-volume/low-price and low-volume/high-price products. Efficient transport and logistics* in and between the different parts of the value chain was also mentioned as important, as well as *collaboration* about all these important aspects.

Based on all of the above, it was considered important to include the subdomain of 'Financial performance' from the WOS-SA in the WOS-MA. As many aspects of importance for this are elaborated in other subdomains, and most importantly; as there was found no need to modify the description of this subdomain for the subdomain to capture all these aspects and be applicable to the macroalgae aquaculture industry, the aspects are not elaborated any further.

Wealth distribution

In the WOS-SA, the subdomain of 'Wealth distribution' encompasses how companies distribute their wealth in the local, regional or national community, such as for example through municipal taxes. In the case of the macroalgae aquaculture industry, it was mentioned by one of the interviewees that a potential positive economic effect of this industry on the society is that macroalgae companies operating in districts and local communities will contribute to *increased tax incomes* for local municipalities. Two others also mentioned that macroalgae companies should aim to contribute with positive economic effects on the society in the form of *donating parts of their profits* to their local communities, for example to schools (see 'Community contributions'), something which also can be regarded as a form of wealth distribution. All this is of course provided that the companies actually become financially profitable (see 'Financial performance').

Other than this, wealth distribution specifically in the context of the macroalgae aquaculture industry was not a main aspect of focus among the interviewees. However, as this can be regarded as a general aspect relevant for all types of companies, and as it was considered important for economic sustainability of the salmon aquaculture industry by the creators of the WOS-SA, it was therefore considered important to include this subdomain also in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Indirect effects on economic activity

In the WOS-SA, the subdomain of 'Indirect effects on economic activity' encompasses investments done by companies in public infrastructure that benefits local communities, but also broader ripple effects of their activities such as establishment of local businesses throughout their supply chain, or other businesses funded by aquaculture money. This aspect, particularly in the form of investments done by companies, can also be considered relevant for all types of companies and industries, however, it may, particularly in the form of generation of ripple effects, be considered of particular relevance for aquaculture and other seafood industries. This is because the seafood industries typically give rise to ripple effects across the entire spectrum of other industry groups, and the different companies and industries that have already established throughout the supply chains of the existing seafood industries have together, due to this, become increasingly important actors in the Norwegian business sector over the whole country (Richardsen, Myhre, Bull-Berg, & Grindvoll, 2018).

In the context of the macroalgae aquaculture industry specifically, a few of the interviewees referred to these positive ripple effects of the aquaculture and other seafood industries and pointed out that the macroalgae aquaculture industry potentially can contribute to additional of such ripple effects, where a concrete example of such that were mentioned were *establishment of businesses producing technology and equipment to this industry* (see also 'Investments in technology & innovation'). It was further emphasised that this could be an important contribution to creation of even more available jobs in addition to those connected to the actual macroalgae aquaculture industry, including in districts and local communities (see 'Labour & employment').

Based on all this, it was considered important to include the subdomain of 'Indirect effects on economic activity' including all its relevant aspects, from the WOS-SA in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Investments in technology & innovation
Engagement in research and development (R&D) to develop new technology and industrial processes is an important part of the activities of many different companies and industries. This aspect was emphasised by many of the interviewees as being of great importance also for the macroalgae aquaculture industry, and it is important to elaborate here that it was mentioned as particularly important for the Norwegian macroalgae aquaculture industry at current times. The reason for this was explained to be that, as opposed to for example the well-developed salmon aquaculture industry, the Norwegian macroalgae aquaculture industry is currently still in a start-up phase where a lot of automated and efficient technology and industrial processes specifically applicable to this industry still are needed for this industry to be able to reduce time-consuming and laborious work required to be done by (too much) labour, something which is particularly important in high-cost countries such as Norway where labour is an expensive production cost (see 'Production costs'), to enable as complete utilisation of all components of the biomass as possible (see 'Resource efficiency' → 'Complete utilisation of the macroalgae biomass', and to scale-up from a largely experimental to an actual commercial and financially profitable production (see 'Financial performance'). Development of technology and industrial processes was also mentioned as important to ensure safe working conditions for employees (see 'Social assurance'), and to ensure as environmentally friendly technologies and processes as possible (see 'Environment').

Regarding whom should *engage* in R&D to develop such new technology and processes, it is important to elaborate here that several of the interviewees mentioned that the companies of the macroalgae aquaculture industry themselves should have a central role in this, but that they preferably should do it in collaboration with each other, and also in collaboration with relevant research institutions and various other actors of the society (see 'Enquiry & learning'). Regarding whom should *invest financially* in this, it is further important to elaborate that several of the interviewees mentioned that the companies of the macroalgae aquaculture industry themselves should have a central role here too, however, that it is particularly important at current times that other actors such as investors and also public authorities contribute with different types of financial support, as the industry still is in this start-up phase having limited means for such investments.

Investment and engagement in R&D to develop such new technology and industrial processes was also found to be addressed as important by the SDGs, most importantly:
- Target 8.2 about the need to achieve higher levels of economic productivity through, among other things, technological upgrading and innovation (United Nations, 2020e).
- Target 9.4 and 9.5 about the need to, among other things, adopt environmentally sound technologies and industrial processes, and upgrade the technological capabilities of industrial sectors, including by encouraging innovation and increasing the number of R&D workers (United Nations, 2020f).

Based on this, it was considered important to include the subdomain of 'Investments in technology & innovation' from the WOS-SA in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

4.2.3 Culture

The cultural sustainability domain encompasses aspects related to the role and responsibility of a social organisation within the macroalgae aquaculture industry as a social player in relation to the community in which it operates. This subchapter operationalises and justifies seven subdomains designed to be capturing the overall key aspects of this cultural sustainability domain, identified as important to consider in the endeavour to understand and ensure sustainability of the macroalgae aquaculture industry. It is important to point out here that this subchapter is less comprehensive and detailed than the other subchapters of this chapter concerning the other sustainability domains of the WOS-MA, particularly environmental sustainability. This is because there was much less focus among the interviewees on cultural sustainability than on other sustainability aspects, and, most importantly; because most cultural aspects, as opposed particularly to many environmental aspects, were found to be of a largely general character being of similar importance regardless of aquaculture type (and in most cases even regardless of industry type), and are described in a general way in the WOS-SA. Thus, no modifications of the WOS-SA were found to be required to make this domain be specifically applicable to the macroalgae aquaculture industry. This does not mean, however, that these aspects are assigned any less importance, weight, or value than other sustainability aspects of the WOS-MA.

Enquiry & learning

In the WOS-SA, the cultural subdomain of 'Enquiry & learning' encompasses companies' engagement in research and development (R&D), and it is thus closely related to the economic subdomain of 'Investments in technology & innovation'. However, where the latter is mainly concerned with companies' engagement in R&D to develop new technology and industrial processes and the financial investments related to this, which are aspects of particular importance for economic sustainability of the companies themselves, 'Enquiry & learning' emphasises more the importance of companies' engagement in R&D in general and particularly through collaboration with various other actors of the society, for shared knowledge-building and dissemination about aspects of importance and interest to both the companies themselves and to the broader society.

This was found to be an important aspect also for the macroalgae aquaculture industry. Firstly, in addition to be emphasising the importance of engagement in R&D to develop new technology and industrial processes, several of the interviewees also emphasised the importance of *engagement in R&D to increase the knowledge about many other aspects of the industry*, particularly many environmental aspects (see 'Environment'), to be able to address such aspects in a knowledge-based and productive way, something which is of interests to both the industry and the broader society. It was further emphasised by several of the interviewees that the companies of the macroalgae aquaculture industry themselves should have a central role in engagement in R&D in general, but that it is important that the different companies regard each other as collaborators instead of competitors and that they engage in such R&D in *collaboration with each other* – something which was a key to the (economic) success of the salmon aquaculture industry – as this will be much more productive and beneficial for all than if every single company should find out everything and solve every challenge all by themselves.

It was further pointed out that macroalgae companies should engage in such R&D also in *collaboration with relevant research institutions and also various other actors of the society*, such as governments, universities and schools and local communities, as this is important for generating holistic and useful knowledge and technology where different actors can contribute with multiple relevant perspectives and expertises, and for knowledge to be disseminated out from the industry, and research institutions, to other relevant actors, such as exactly governments, universities and schools and the society. The latter was emphasised by several as important for generation of acceptance and support of the industry.

Based on this, it was considered important to include the subdomain of 'Enquiry & learning' from the WOS-SA in the WOS-MA, and that there was no need for any modifications of it to make it be applicable to the macroalgae aquaculture industry.

Community integration

In the WOS-SA, the subdomain of 'Community integration' emphasises the importance of fostering a sense of identity and integration between a company and the local community, and hereunder also between a company and its employees. In the context of the macroalgae aquaculture industry, one of the interviewees mentioned that it is important that macroalgae companies try to create a *feeling of a kind of relationship or ownership*, which may be understood as a form of identity or integration, *among local communities to macroalgae companies*, particularly since these companies are operating within such communities and are utilising their and the broader society's shared resources. This was further described as a feeling that these companies do something meaningful such as producing meaningful products through sustainable utilisation of the shared resources, that they mean something to and otherwise may contribute positively to these communities (see for example 'Community contributions' and 'Social capital of local community'), and that the communities, including individual persons may have a possibility of participating in the industry (see also 'Representation & negotiation'), instead of feeling that the companies have just come into their communities "from the outside" and started utilising the shared resources for their own success only.

Other than this, the importance of community integration specifically in the context of the macroalgae aquaculture industry was not a major aspect of focus among most of the interviewees, and it was also difficult to find literature addressing exactly this. However, this information from one of the interviewees was still considered to be an important support of the importance of this aspect also for the macroalgae aquaculture industry, together with the recognition that this reasonably can be regarded as a somewhat general aspect being of importance for many types of companies and industries, maybe particularly for companies and industries that operate within local communities and utilise these communities' and the broader society's shared resources. Based on this, it was considered important to include the subdomain of 'Community integration' in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Community contributions

The subdomain of 'Community contributions' in the WOS-SA is emphasising that a company should aim to actively make positive contributions to its local community. Such positive contributions from companies to local communities were mentioned by a few of the interviewees as important also for the macroalgae aquaculture industry. One of them mentioned that contributions, for example in the form of *events arranged by companies* with the aim of creating contact and sharing knowledge between the companies and the communities, could be important to create a sense of identity and integration between the companies and communities (see 'Community integration').

Two other interviewees mentioned that macroalgae companies also should aim to make positive contributions to their local communities in the form of *donating parts of their profits* to these communities, for example to schools (something which can be regarded as a form of wealth distribution; see 'Wealth distribution'). It was emphasised in this context, however, that this may not be relevant at current times, as most of the companies of the macroalgae aquaculture industry actually are not financially profitable yet (see 'Financial performance').

In the same way as with the aspect of 'Community integration', the importance of community contributions specifically in the context of the macroalgae aquaculture industry was, other than this, not a major aspect of focus among most of the interviewees, and it was also difficult to find literature addressing exactly this. However, this information from these interviewees was still considered to be an important support of the importance of this aspect also for the macroalgae aquaculture industry, together with the recognition that this aspect too reasonably can be regarded as a general aspect being of relevance for many types of companies and industries. And as this aspect too was considered important for cultural sustainability of the salmon aquaculture industry by the creators of the WOS-SA, it was considered important to include the subdomain of 'Community contributions' in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Social capital of local community

In the WOS-SA, the subdomain of 'Social capital of local community' includes how a company attempts to sustain and promote the social capital of the local community, or in other words; the social fabric of the community, such as for example resources, relationships, social networks, and adaptive capacity. This subdomain is with this emphasising both the importance of limiting any potential negative impacts of companies on local communities, and also, on the other side, the importance of actively promote positive effects on them.

In the context of the macroalgae aquaculture industry, it was, as described in the subdomain of 'Labour & employment', many of the interviewees who mentioned that creation of available jobs, and particularly creation of available jobs in districts and local communities, is an important potential positive effect of this industry (on an industry level) because this will be a strong contributor to make people able to live in such places instead of being forced to move to centralised places to have an income. And as people can be regarded as an essential part of any community, such creation of available jobs by industries in local communities making people able to live here can thus be regarded as an essential way to sustain and promote the social capital of such communities.

It is important to elaborate here, again, that one of the interviewees emphasised the importance of ensuring that the companies of the industry are not too large, and keeping not only the cultivation of the macroalgae, but also other parts of the value chain, and also the administration and ownership of the different companies, within such local communities, because this would be a (further) essential way to promote the social capital of these communities. This was explained to be so both in the sense that this would make even more people, but also even more people with a greater diversity of skills and competences able to live here, something which may constitute important resources for these communities, and also in the sense that this would ensure a closer contact between the companies and the communities, something which may make the companies more likely to engage in the communities, potentially promoting various aspects of their social capital.

Other than this, it was few of the interviewees who focused explicitly on the importance of sustaining and promoting various aspects of the social capital of local communities. However, the strong focus of one of the interviewees on this aspect, and also the fact that this aspect can be understood as being addressed, to a certain extent, by the ASC-MSC Seaweed Standard, was still considered to be a support of the importance of this aspect also for the macroalgae aquaculture industry. Together with the additional recognition that this aspect, too, like most other cultural sustainability aspects, reasonably can be regarded as a general aspect being of relevance for many types of companies and industries, and the fact that this aspect was considered important for cultural sustainability of the salmon aquaculture industry by the creators of the WOS-SA, it was considered important to include the subdomain of 'Social capital of local community' also in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Equity

The subdomain of 'Equity' in the WOS-SA includes how a company and the [salmon aquaculture] industry may be seen to be upholding and improving the social structures and collective capabilities of local communities, such as gender equality, age non-discrimination and by ensuring a generational approach. In this study, no aspects related to this subdomain were a focus area of any of the interviewees, and it was also difficult to find literature addressing the importance of equity specifically in the context of the macroalgae aquaculture industry. However, as equity, as it is described in the WOS-SA, can be understood as a general aspect of importance for all types of companies and industries as social players in relation to the communities in which they operate and was considered important for cultural sustainability of the salmon aquaculture industry by the creators of the WOS-SA, it was considered important to include this subdomain also in the WOS-MA and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry. Different aspects of equity are furthermore largely addressed as important by a number of the goals and targets of the SDGs (United Nations, 2020m), something which also supported this consideration.

Respect for native culture
The subdomain of 'Respect for native culture' in the WOS-SA is concerned with ensuring that a company's activities respect, value and promote the ancestral culture of the region, as many aquaculture operations are placed in areas that are claimed as traditional territories or where indigenous groups are present. In the same way as with the subdomain of 'Equity', no aspects related to this subdomain were a focus area of any of the interviewees interviewed in this study. It is important to mention here, however, that although many aquaculture operations may be placed in such areas, including many macroalgae aquaculture operations as supported by the fact that the aspect of 'Rights of indigenous people' is addressed by the ASC-MSC Seaweed Standard, this may not be of particular relevance for the Norwegian macroalgae aquaculture industry, as there are few such areas in Norway. However, it was considered that this aspect nevertheless cannot be considered complete irrelevant for this industry such as for example the aspect of 'Feed' was considered to be, and as this aspect was considered important for cultural sustainability of the salmon aquaculture industry by the creators of the WOS-SA, it was therefore included in the WOS-MA, without any modifications.

Employee interests & well-being
In the WOS-SA, the subdomain of 'Employee interests & well-being' includes how a company ensures the well-being of its employees, beyond basic rights of employment (see 'Social assurance'). In the context of the macroalgae aquaculture industry, it was mentioned by some of the interviewees that it is important for employees to feel that they have a meaningful job, and that this industry has a great potential of ensuring this both because it aims to produce something that is actually needed (food, feed, etc.) and because there are few negative, and instead many positive, effects of this industry compared to many other industries, particularly with regards to environmental effects (see 'Environment'). Except from this, and the importance of ensuring employees' possibilities of influence (see 'Representation & negotiation'), no other aspects related to 'Employee interests & well-being' were a focus area among the interviewees. However, as this aspect, like most other aspects of cultural sustainability, reasonably can be understood as relevant for all types of companies and industries and was considered important for cultural sustainability by the creators of the WOS-SA, it was still considered important to include this subdomain also in the WOS-MA, without any modifications to make it applicable to the macroalgae aquaculture industry.

4.2.4 Governance

The governmental sustainability domain encompasses aspects related to how public goods and services are provided and regulated. This includes how an industry, in this case the macroalgae aquaculture industry, is regulated on a national level, but encompasses also the norms and practices initiated on a local and company level. This subchapter operationalises and justifies seven subdomains designed to be capturing the overall key aspects of this governmental sustainability domain, identified as important in the endeavour to understand and ensure sustainability of the macroalgae aquaculture industry. It is important to point out here that this subchapter, too, is much less comprehensive and detailed than the first subchapter of this chapter concerning environmental sustainability in the WOS-MA. This is mainly because most governmental aspects, as opposed to many environmental aspects, were found to be of a largely general character being of similar importance regardless of aquaculture type (and in many cases even regardless of industry type), and are described in a general way in the WOS-SA. Thus, only a few minor modifications of the WOS-SA were found to be required to make this domain be specifically applicable to the macroalgae aquaculture industry. This does not mean, however, that these aspects are assigned any less importance, weight, or value than environmental aspects of the WOS-MA.

Accountability & enforcement

The subdomain of 'Accountability & enforcement' in the WOS-SA emphasises the importance of a company's knowledge of and compliance with all applicable national and local regulations and rules, as well as whether or not a company has internal requirements to behaviour, and/or internal audits. In this study, several of the interviewees mentioned, in different contexts, that there are a lot of both general and specific regulations and rules applicable to the macroalgae aquaculture industry just as there are for other industries, such as for example general regulations concerning environmental protection (for example the Pollution Control Act and Nature Diversity Act) and basic rights of employment (for example the Working Environment Act), and more specific regulations for aquaculture (the Aquaculture Act). In these contexts, the importance of the macroalgae aquaculture industry's *knowledge of and compliance with such regulations and rules* was largely mentioned as a matter of course. The same can also be said about the importance of the *presence of internal requirements to behaviour, and/or internal audits*. It is important to elaborate here that it was mentioned by several that much of the more specific regulations for aquaculture are specific for aquaculture with salmon, but not so specific for aquaculture with macroalgae, and thus, that there may be a need for modifications of some of these regulations to make them be more specifically applicable to this industry. It was in this context emphasised, however, that all regulations and modifications of such must be knowledge-based, and thus, that they must be made in line with development of knowledge (see 'Enquiry & learning').

Together with the fact that several aspects included in the subdomain of 'Accountability & enforcement' are also addressed by the ASC-MSC Seaweed Standard, this was considered to be an important support of the importance of this subdomain also for the macroalgae aquaculture industry. It was therefore considered important to include this subdomain in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Social assurance
In the WOS-SA, the subdomain of 'Social assurance' includes the assurance of basic rights of employees, including health and safety aspects, based on national regulations and as stated by the International Labour Organisation (ILO). Such rights can reasonably be considered important for all types of employees, and thus, they can be considered important not only in the salmon aquaculture industry, but in all types of industries requiring labour and employment, including also the macroalgae aquaculture industry.

Such rights were initially not a subject of focus among the interviewees interviewed in this study, however, on some direct questions potentially being related to this, such as for example questions about if there are any "social aspects" of importance for sustainability of the macroalgae aquaculture industry, several aspects related to such basic rights of employees were mentioned by several of the interviewees largely as a matter of course. Most of them had in this context a particular focus on the importance of *assurance of health and safety aspects*, as they explained that the type of work required to be done particularly in the cultivation phase of the macroalgae aquaculture industry, just as in the salmon aquaculture industry, is a quite dangerous type of work – actually is the work required in the aquaculture industries found to be the second most dangerous type of work in Norway after the work required in the fisheries, with regards to both the risk of getting injuries and of dying at work (Thorvaldsen, Holmen, & Kongsvik, 2017). Assurance of various health and safety aspects was therefore emphasised as very important for this industry.

Assuring basic rights of employees, including health and safety aspects, is also to a great extent addressed by the ASC-MSC Seaweed Standard, and not the least emphasised as important for sustainability by the SDGs, particularly through:
- Target 8.7 and 8.8 about the need to take immediate and effective measures to eradicate forced labour, end modern slavery and human trafficking and secure the prohibition and elimination of the worst forms of child labour, and by 2025 end child labour in all its forms, and to protect labour rights and promote safe and secure working environments for all workers (United_Nations, 2020e).

Based on all this, it was considered important to include the subdomain 'Social assurance' from the WOS-Sa also in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

Food safety
The aspect of 'Food safety' was a subject of strong focus among almost all of the interviewees interviewed in this study. It was emphasised by some that this is an important aspect in general for everyone producing anything that is to be used for food or feed purposes to ensure the health of the consumers, something which also is addressed by the SDGS, particularly through target 2.1 about the need to, among other things, ensure access by all people to safe food all year round (United Nations, 2020a). In the case of the macroalgae aquaculture industry specifically, most of the interviewees did, however, refer particularly to the fact that due to macroalgae's efficient ability to absorb inorganic compounds from their surrounding waters (see 'Abiotic effects' → 'Absorption of inorganic nutrients'), they are able to absorb many different types of *pollutants* from these waters (see 'Abiotic effects' → 'Absorption of pollutants') which may pose a major risk to the health of consumers of macroalgae food and feed products, where different types of heavy metals are of particular concern (Duinker et al., 2016).

It was furthermore referred to the fact that macroalgae, particularly brown macroalgae, also contain very high levels of *iodine* – so high that only a small intake of dried brown macroalgae may contribute with an excessive iodine intake (Duinker et al., 2016). It was emphasised that the knowledge about these aspects currently is limited, but that they nevertheless should be considered when producing macroalgae for food or feed purposes.

In addition to this, some of the interviewees also mentioned that the food safety aspect of *allergens* also is of importance for this industry. This was explained to be so because as macroalgae are cultivated in open waters, both fish and crustaceans can meddle into the macroalgae biomass during cultivation and harvest and follow it into processing, and thus, macroalgae food products may contain traces of such fish and crustaceans, to which some people can be (seriously) allergic. Due to this, these interviewees emphasised that macroalgae food products should be regarded as seafood, not vegetables, and that they should be labelled with information about possible allergens.

Based on this, it was considered important to include the subdomain of 'Food safety', including all possible aspects of relevance for this, from the WOS-SA in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry. It is important to note here, however, that this aspect will not be relevant for macroalgae companies producing macroalgae biomass for use in other types of products than food and feed products and related products, such as for example macroalgae biomass produced for use as biofuel.

Transparency & traceability

Transparency and traceability, understood as openness for example surrounding a company's operations and decision-making processes, and the ability to follow the movement of a company's products through their various stages of production, are by many regarded as important aspects of sustainability in general, and they were in this study identified as important also for sustainability of the macroalgae aquaculture industry specifically. Transparency, or *openness*, in particular, was mentioned by several of the interviewees as essential for many other sustainability aspects of this industry, such as for example for *enabling coordination and collaboration about different interests and activities* (see 'Coordination & collaboration about interests & activities') such as for example research and development (see 'Enquiry & learning'), for *ensuring participation and influence of various stakeholders* (see 'Representation & negotiation'), both with regards to operations and decisions made by the companies of the industry, and also to decisions made by public authorities concerning the industry, such as for example decisions related to granting of licenses and permits (see 'License & permit conditions'), for *ensuring consumers* for example that products are safe to consume (see 'Food safety'), and for *fostering acceptance, and also a sense of identity or integration with the industry among local communities* (see 'Community integration'), for example through inviting people in for "guided tours" and sharing of information at facilities.

Justification of modifications of the original subdomain

Together with the fact that the importance of transparency and traceability is also addressed by the ASC-MSC Seaweed Standard, and the recognition that these aspects reasonably can be regarded as general aspects being of relevance for many types of companies and industries, this was considered to be an important support of the importance of the subdomain of 'Transparency & traceability' from the WOS-SA for the macroalgae aquaculture industry just as for the salmon aquaculture industry.

It was therefore considered important to include this subdomain also in the WOS-MA. It was also considered that the original description of this subdomain is capturing the scope of these aspects very well – except from that it seems to focus on transparency and traceability related to companies only. Thus, to ensure the inclusion of transparency in particular, also related to regulation of the industry, as mentioned as important by some of the interviewees, it was considered necessary to make a few modifications in the description. These can be seen in the following:

WOS-SA:
This subdomain includes how the aquaculture company allows for openness surrounding daily operations, and the decision-making process. This also includes the accessibility and circulation of information, both on own initiative and on request. Additional information may include e.g. degree of accessibility, available information channels, choice of language, and format. Both internal transparency within the company and external transparency towards the public, as well as record-keeping are part of this subdomain.

WOS-MA:
This subdomain includes how openness surrounding operations and decision-making processes are allowed for. This also includes the accessibility and circulation of information, both on own initiative and on request. Additional information may include e.g. degree of accessibility, available information channels, choice of language, and format. Both internal transparency within companies and institutions and external transparency towards the public, as well as record-keeping, are part of this subdomain.

Representation & negotiation
The subdomain of 'Representation & negotiation' in the WOS-SA includes the participation and influence of all types of stakeholders, including the local community, facilitated and encouraged through allowing for sufficient access to information and available forums where interests and concerns can be communicated and discussed, as well as the presence of resources and capacity to receive and process criticism and complaints. Like many other aspects of governmental sustainability, these aspects can also reasonably be regarded as general aspects of relevance for many types of companies and industries, and thus, also for the macroalgae aquaculture industry.

This seemed to be found true in this study in the sense that some of the interviewees mentioned that it is important both to *inform* (see 'Transparency & traceability') and to *consult with various stakeholders*, including for example NGOs and local communities, both regarding decisions about the industry made by public authorities such as for example where facilities should be allowed to be placed (see 'Siting' and 'Coordination & collaboration about interests & activities'), and regarding decisions about the industry made by the companies themselves. This was mentioned by these interviewees as important particularly to avoid conflicts and ensure democratic processes regarding how society's shared resources, in the form of both shared marine spaces and shared marine biomass resources being utilised by the industry, should be utilised. It was, however, also mentioned by some that there is not going to be any macroalgae aquaculture industry if every single cottage owner in the country is upheld in protests against the placing of facilities in their nearby bays, and thus, that it also is important that decisions, after being discussed in democratic processes, in the end are made based on knowledge.

It was further explicitly emphasised by one of the interviewees that it is of great importance also for *employees to feel that they have a possibility of participating in and having an influence on the companies and the industry that they are a part of,* and that local production and ownership, and close contact between the administration and owners of the companies and their employees is essential to ensure this.

The importance of ensuring inclusive decision-making processes is also addressed by the ASC-MSC Seaweed Standard, and by the SDGs, particularly through the targets:
- 9.2 about the need to promote inclusive industrialisation (United Nations, 2020f), and
- 16.7 about the need to ensure responsive, inclusive, participatory and representative decision-making at all levels (United Nations, 2020k).

Justification of modifications of the original subdomain
Based on all this, it was considered important to include the subdomain of 'Representation & negotiation', including all possible aspects of relevance for this, from the WOS-SA in the WOS-MA – but some modifications were made in the description of the subdomain to ensure inclusion of representation and negotiation aspects not only related to companies, but also related to regulation of the industry. These are as follows:

WOS-SA:
This subdomain includes the presence and influence of stakeholders facilitated through available forums where different interests and concerns can be communicated and discussed. It also contains the encouragement of participation and inclusion of the local community through access to information regarding the company's operations, intentions, and plans. Resources and capacity to receive and process criticism and complaints, and evidence of how such conflicts are handled is also included.

WOS-MA:
This subdomain includes the presence and influence of stakeholders facilitated through available forums where different interests and concerns can be communicated and discussed. It also contains the encouragement of participation and inclusion of stakeholders through access to information regarding operations, intentions, and plans. Resources and capacity to receive and process criticism and complaints, and evidence of how such conflicts are handled is also included.

Coordination & collaboration about interests & activities
Due to macroalgae's dependence on sunlight (see 'Abiotic effects' → 'Absorption of sunlight'), macroalgae aquaculture is a space-intensive industry which may come in conflicts with other users of the coastal zone (Hancke et al., 2018; Skjermo et al., 2014; Stévant et al., 2017). To avoid such conflicts, several of the interviewees mentioned, supported by the ASC-MSC Seaweed Standard and literature (Hancke et al., 2018; Skjermo et al., 2014; Stévant et al., 2017) that *good coordination with other activities and users in the area*, particularly through *participatory* (see 'Representation & negotiation') *marine spatial planning* as conducted by public authorities, is essential. In this context, it should be elaborated that the possibility of *placing macroalgae aquaculture facilities off-shore* was mentioned by several of the interviewees as a promising solution to this, although it was emphasised that this requires significant technical innovation (see 'Investments in technology & innovation') and may not be possible until several years in the future. It should also be elaborated that some also mentioned *integration of macroalgae aquaculture with other types of industries* as another solution, such as IMTA, or even integration of macroalgae aquaculture facilities

with oil platforms and/or windmill facilities off-shore (see 'Resource efficiency' for more details) – although the latter also was emphasised as a potential solution for the future.

It should here further be mentioned that not only coordination, but also *collaboration, both between macroalgae companies and between macroalgae companies and other industries, about many types of resources, interests and activities* was emphasised by several of the interviewees as important in general. This was explained to be so for several other reasons than just avoidance of conflicts about areas of the coastal zone, such as for example for *ensuring efficient use of resources* to save both the environment and individual production costs (see 'Resource efficiency' and 'Production costs'), and for *efficient and shared development and dissemination of technology and knowledge* being of interest to both all companies of the macroalgae aquaculture industry themselves and to the broader society (see 'Enquiry & learning').

The importance of collaboration is not the least addressed by a number of the goals and targets of the SDGs, particularly by goal 17 about the need for a global partnership for sustainable development, and its targets:
- 17.16 about the need to enhance the global partnership for sustainable development, complemented by multi-stakeholder partnerships that mobilize and share knowledge, expertise, technology and financial resources, to support the achievement of the sustainable development goals in all countries, and
- 17.17 about the need to encourage and promote effective public, public-private and civil society partnerships, building on the experience and resourcing strategies of partnerships (United Nations, 2020l).

Justification of modifications of the original subdomain
Based on all this, it was considered important to include the subdomain of 'Coordination of interests & activities' from the WOS-SA also in the WOS-MA. However, it was considered important to emphasise the importance of collaboration to a greater extent, and not only between macroalgae companies, but also between macroalgae companies and other industries. Therefore, some modifications of both the title and the description of this subdomain were made. These can be seen in the following:

WOS-SA:
Coordination of interests & activities
This includes coordination with other activities in the area, such as fisheries, recreation, and tourism, such as planning capacity and willingness to deal with conflicts from multiple uses of marine space and resources, e.g. conflicts of interest, displacement of other activities, and general loss of amenity. Also, coordination and collaboration with nearby aquaculture facilities and their production is included. Participatory marine spatial planning, as instigated by government or by shared agreement, is also included.

WOS-MA:
Coordination & collaboration about interests & activities
This subdomain includes coordination with other activities in the area such as other aquaculture facilities, fisheries, recreation, and tourism, such as planning capacity and willingness to deal with conflicts from multiple uses of marine space and resources, e.g. conflicts of interest, displacement of other activities, and general loss of amenity. This includes also participatory marine spatial planning, as instigated by governments or by shared agreement. Also, collaboration about various activities and interests, both between macroalgae companies and between macroalgae companies and other industries and actors, is underneath this subdomain.

Siting

According to the Norwegian Aquaculture Act, all who have been granted a permit by the public authorities to start with any form of commercial aquaculture production in Norway, whether with fish, crustaceans, macroalgae or other types of marine organisms, have been given the right to such commercial aquaculture production of a specific species at a defined geographical location (NFD, 2005) (see 'License & permit conditions'). For the public authorities to allow such production at such a defined geographical location, the location must be regulated for aquaculture, either for aquaculture in general or for aquaculture with macroalgae specifically, according to the relevant municipality's coastal zone spatial plans (Chapman et al., 2018). Several of the interviewees interviewed in this study mentioned several aspects of importance regarding which and how such locations should be chosen and regulated for aquaculture with macroalgae, where they had a particular focus on the need to ensure *locations with optimal conditions for growth* for contributing to financial profitability of the industry (see 'Financial performance'), *locations where potential negative effects on plant health* (see 'Plant health') *and the surrounding environment* (see 'Abiotic effects' and 'Biotic effects') *are being limited as much as possible*, and also *locations where absorption of pollutants are being limited, if the macroalgae biomass is to be used for food or feed purposes* (see 'Food safety'). Also, the need to *ensure that local communities and various other stakeholders are informed and consulted* before deciding on locations (see 'Representation & negotiation') was emphasised as important. It should be elaborated here that several of the interviewees mentioned that, luckily, most conditions optimal for growth of the macroalgae are also often optimal for limitation of potential negative effects on plant health and the surrounding environment, which may make decisions on locations easier. As an example, the presence of sufficient water flows at a location was mentioned as important both for macroalgae's absorption of the nutrients they need for growth and good health (see 'Abiotic effects' → 'Absorption of inorganic nutrients'), and for limitations of potential negative effects of releases of POM (see 'Abiotic effects' → 'Release of particulate organic matter'), altering of hydrologic conditions (see 'Abiotic effects' → 'Altering of hydrologic conditions'), and other environmental aspects.

Based on this, it was considered that the subdomain of 'Siting' from the WOS-SA is just as relevant for the macroalgae aquaculture industry as for the salmon aquaculture industry, that it was important to include this subdomain in the WOS-MA, and that there was no need for any modifications of its description to make it be applicable to the macroalgae aquaculture industry.

5 Discussion

This chapter provides a discussion of the results of the study presented in this thesis, that is; of *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)* as a modified version of *the Wheel of Sustainability for salmon aquaculture (WOS-SA)* (subchapter 5.1), and of how a sustainable macroalgae aquaculture industry, as defined by the WOS-MA, can contribute to the Sustainable Development Goals (SDGs) and global sustainable development (subchapter 5.2). Additionally, a discussion of the reliability and validity of the study is provided in subchapter 5.3.

5.1 The Wheel of Sustainability for macroalgae aquaculture

This subchapter provides a discussion of the new WOS-MA as a modified version of the original WOS-SA. This includes both a discussion of the content of each of the four main sustainability domains of the WOS-MA based on the data obtained in this study and compared to the content of the WOS-SA (subchapters 5.1.1, 5.1.2, 5.1.3 and 5.1.4), a discussion of the WOS-MA as a holistic and complexity-based model of sustainability (subchapter 5.1.5), and considerations about how the WOS-MA can be applied in the endeavour to understand and ensure a sustainable macroalgae aquaculture industry (subchapter 5.1.6).

5.1.1 Environment

As already described in the results of this study; environmental sustainability aspects, and particularly effects on abiotic and biotic components of natural ecosystems generated by the cultivated macroalgae, were the subject of the definitely strongest focus both among most of the interviewees interviewed, and in the literature reviewed in this study. There may be several reasons for this, where one may be that there may be a strong focus on environmental sustainability among many people in general today, which may have to do with the fact that the current understanding and definition of the concept of sustainability on which the SDGs are based, is assigning environmental sustainability a fundamentally more important role than have been done before, due to the recognition of its fundamentally important role for the sustainability of the Earth system as a whole, and at the same time, of humanity's significant negative effects on it (Griggs et al., 2013; Rockström et al., 2009; Sachs, 2015; Steffen et al., 2015; Steffen et al., 2004). A second reason may be that some of the most well-known negative sustainability aspects associated with aquaculture in general, and particularly salmon aquaculture, are, exactly, environmental sustainability aspects such as escapes and genetic pollution of wild populations, lice and diseases, pollution from aquaculture facilities and unsustainable feed sources (Klinger & Naylor, 2012). And as macroalgae aquaculture also is a form of aquaculture, it may be natural to compare this industry to the salmon aquaculture industry, and focus on the same type of sustainability aspects. Thirdly, environmental sustainability aspects in the form of effects on abiotic and biotic components of natural ecosystems generated by the cultivated macroalgae are, as found in this study, the sustainability aspects that are the most specific of all for the macroalgae aquaculture industry differentiating this industry from other industries, and at the same time, the current knowledge about such effects is relatively limited. Thus, it might have been important for the interviewees, and the literature, to have a main focus on these.

Based on the information obtained from the interviewees and the literature, all the environmental sustainability subdomains of the original WOS-SA identified as important for sustainability of the salmon aquaculture industry, except from the subdomain of 'Feed', were, as the results show, found to be relevant also for sustainability of the macroalgae aquaculture industry, and thus, they were included in the new WOS-MA. This shows that the overarching types of environmental aspects (here in the form of subdomains) are largely the same for these two related industries. However, as the results also show; almost all of the subdomains had nevertheless to be modified, and some in quite significant ways, to make them, and the new WOS-MA, be specifically applicable to the macroalgae aquaculture industry. This further shows that there nevertheless are some significant differences between these two industries with regards to the more concrete aspects pertaining to each of these overarching types of environmental aspects.

Regarding the two first environmental subdomains; 'Abiotic effects' and 'Biotic effects', the operationalisation of these subdomains specifically for the macroalgae aquaculture industry shows that the main reason for this is that macroalgae, being photoautotrophic organisms, or producers, and salmon, being heterotrophic organisms, or consumers, are fundamentally different types of organisms which affect abiotic and biotic components of their surrounding environment in several fundamentally different ways – in several cases in complete opposite ways. This was found to be particularly the case for effects generated by the cultivated, or farmed, organisms on abiotic components, but to some extent also for effects on biotic components. Considered most importantly, this involves that even though macroalgae aquaculture, just like salmon aquaculture, potentially can generate several negative effects on such components that must be minimised to ensure environmental sustainability of this industry, macroalgae aquaculture, as opposed to salmon aquaculture, can potentially also generate several positive effects on such components. And as not only minimisation of negative effects, but also exactly creation and maximisation of positive effects, potentially being of shared value for both industries, and the environment and the broader society, is emphasised as important for companies and industries to truly ensure and increase their sustainability (Porter & Kramer, 2006) and to contribute to the SDGs and global sustainable development (GRI, UN Global Compact, & WBCSD, 2016), it was considered important to make some modifications of the original descriptions of the subdomains of 'Abiotic effects' and 'Biotic effects' from the WOS-SA, to ensure their inclusion of not only potential negative effects, but also potential positive effects in the WOS-MA. This constitutes a significant difference between these two related industries, and indicates that the macroalgae aquaculture industry has an even greater potential to be an environmental sustainable industry and to contribute to global environmental sustainable development than the salmon aquaculture industry. It is, however, important to emphasise here that whether aquaculture with macroalgae will generate negative or positive effects on abiotic and biotic components was found to be dependent on many factors, particularly on existing environmental conditions, the scale of facilities and activities, and the intensity of the production, at a specific location. This further indicates the importance of knowledge-based and good governance of the industry to actually ensure minimisation of negative effects and maximisation of positive effects (see subchapter 5.1.5). It is important also to emphasise, again, that the knowledge about both abiotic and biotic effects currently is relatively limited, something which also indicates the need for more research on this.

The identified fundamentally different nature of macroalgae and salmon is also the reason why the environmental subdomain of 'Fish health & welfare' was modified to be titled 'Plant health' including only relevant aspects of 'plant health' for macroalgae and no aspects related to 'plant welfare', and why the environmental subdomain of 'Feed' was considered irrelevant for the macroalgae aquaculture industry and thus excluded from the WOS-MA. It is not the least the reason why it can be argued that aquaculture with macroalgae should rather be compared to agriculture with terrestrial plants (except from the positive fact that aquaculture with macroalgae, as opposed to agriculture with terrestrial plants, are not requiring any arable lands, fertilizers, pesticides or fresh water, in addition to not be requiring any feed) instead of with aquaculture with salmon (however, food containing macroalgae should still be regarded as seafood due to its potential content of allergens). This was also argued by some of the interviewees.

Regarding the rest of the environmental subdomains, these are primarily concerning environmental aspects not generated directly by, or being dependent on, the specific type of organism being cultivated, or farmed, something which means that the fundamentally different nature of macroalgae and salmon is not the reason why most of these subdomains had to be modified to make them, and the new WOS-MA, be specifically applicable to the macroalgae aquaculture industry. The main reason for this is instead the identified need for these subdomains to be broader and open for inclusion of even more concrete aspects relevant for their overarching type of aspect. This was particularly the case for the subdomain of 'Energy consumption & GHG emissions' from the WOS-SA emphasising the need for efficient and sustainable use of energy, which was included in the WOS-MA, but which had to be retitled to 'Resource efficiency' and broadened in its description to include the need for efficient and sustainable use of not only energy, but of many types of resources, and also to emphasise the possibility and importance of collaboration between both macroalgae companies and between macroalgae companies and other industries, including the salmon aquaculture industry, as a contribution to achieve this. As most other industries, including exactly the salmon aquaculture industry, also are using many such different types of resources and may constitute such potential collaboration partners, the aspect of resource efficiency could reasonably be considered relevant also for them. However, it is not within the scope of this study to discuss why this seem to not have been considered equally important for sustainability of the salmon aquaculture industry by the creators of the WOS-SA.

5.1.2 Economics

As already described in the results of this study; the economic sustainability domain encompasses both economic aspects related directly to companies, such as for example aspects related to their financial profitability, but also aspects related to economic effects of companies and industries on the broader society, such as for example ripple effects in the form of local businesses established throughout their supply chain. In addition to the already mentioned environmental sustainability aspects, economic aspects related directly to the companies of the macroalgae aquaculture industry, particularly their financial profitability, were a subject of strong focus, both among most of the interviewees interviewed, and in the literature reviewed in this study. Economic effects of these companies and the industry on the broader society were, on the other side, subjects of much less focus, except from the positive potential effect of creation of available jobs. A main reason for this focus is probably the focus of this study on the Norwegian macroalgae aquaculture industry, because most of the companies of this young and emerging industry are, as found in this study, not financially profitable yet, and, as it was explicitly stated by many of the interviewees: “Without such financial profitability of the companies, there will simply be no macroalgae aquaculture industry” – and thus no economic effects of the industry on the broader society. Financial profitability of the companies can thus be regarded as an essential aspect for sustainability of the industry, and due to this, it was probably considered of great importance to have a main focus on this. In opposition, the well-developed salmon aquaculture industry has already become a significantly financially profitable industry, which makes it more natural to have a great focus also on economic effects of this industry on the broader society.

This does not necessarily mean, however, that economic effects of the Norwegian macroalgae aquaculture industry on the broader society, other than the positive potential effect of creation of available jobs, are not important or even irrelevant for sustainability of this industry. Conversely, it was found in this study that both all economic aspects related directly to companies and also all potential aspects related to economic effects of companies and industries on the broader society, as they are described in the original WOS-SA, are of a general character, at least for aquaculture industries, not being dependent on the specific type of organism being cultivated, or farmed. Rather, they were found to be just as relevant for the macroalgae aquaculture industry as for the salmon aquaculture industry – if the macroalgae aquaculture industry, as desired, too becomes a financially profitable industry in the future. And as the WOS-MA, just like the WOS-SA, is meant to be an adaptive model allowed to be able to be adapted to real-world changes as they occur in the future (see subchapter 2.5 and 5.1.5), it was therefore considered important to include all the economic sustainability subdomains from the WOS-SA which were considered important for sustainability of the salmon aquaculture industry by the creators of the WOS-SA also in the WOS-MA, and that there was no need for any (significant) modifications to make them, and the WOS-MA, be specifically relevant and applicable to the macroalgae aquaculture industry.

In this context, it is important to point out that when economic effects of the macroalgae aquaculture industry on the broader society actually were mentioned, it was emphasised in most of the cases that it is of positive importance that this industry has the potential to generate various positive economic effects not only on the broader society in general, but on districts and local communities specifically, as this is where the cultivation of the macroalgae typically takes place, potentially being an essential contribution to the sustenance and promotion of these communities (thus also potentially being an essential aspect of cultural sustainability of the industry). This was mentioned by several particularly in the context of this industry’s potential of creating available jobs, but also by a few who mentioned this industry’s potential of generating positive ripple effects, and its potential of contributing to increased tax incomes for the municipalities in which the companies operate, as a form of wealth distribution. This mentioned positive importance of such potential positive economic effects of this industry on districts and local communities can be considered supported by the fact that Norway is a country of exactly many districts and local communities, and that it is a political goal in Norway to ensure exactly the sustenance and promotion of these communities (KMD, 2014). This further supports the importance of the inclusion of such types of economic aspects in the WOS-MA just like in the WOS-SA, even though they may not be just as relevant for the macroalgae aquaculture industry as for the salmon aquaculture industry at exactly this point in time. Furthermore, it may be important to include them in the model at exactly this point in time, to be able to start already today with facilitation of such positive economic effects of the industry to occur in the future.

5.1.3 Culture

In opposition to the already mentioned environmental sustainability aspects and aspects related to the financial profitability of the companies of the macroalgae aquaculture industry, cultural sustainability aspects, which together encompass aspects related to the role and responsibility of a social organisation as a social player in relation to the community in which it operates, were in general a subject of very little focus, both among most of the interviewees interviewed, and also in the literature reviewed in this study. One reason for this may be, as explained in subchapter 5.1.1 about the environmental sustainability domain, that the most well-known and discussed sustainability aspects associated with aquaculture in general, and particularly salmon aquaculture, are mainly environmental sustainability aspects (Klinger & Naylor, 2012) and to a very little extent cultural sustainability aspects (Alexander, Amundsen, & Osmundsen, 2020). And as macroalgae aquaculture may naturally be compared to salmon aquaculture, it may be natural to focus on the same type of sustainability aspects. Another reason may be that most such cultural sustainability aspects, as found in this study, seem to be of a (more or less) general character, being of similar relevance not only for the macroalgae aquaculture industry and the salmon aquaculture industry, but for many types of companies and industries. And as the focus of this study was on sustainability of the macroalgae aquaculture industry specifically, the interviewees, and the literature about this specific industry, may have been focused mainly on sustainability aspects that are, exactly, specific for this industry differentiating this industry from other industries, such as for example many environmental sustainability aspects, and not so much on sustainability aspects that are relevant for many different types of industries, such as exactly many cultural sustainability aspects. Furthermore, the focus of this study on the Norwegian macroalgae aquaculture industry specifically may have been an additional, related reason for this, because Norway is a very well-developed country, and thus, many of such cultural sustainability aspects are maybe "taken for granted" in this country, and therefore maybe not emphasised for a Norwegian industry specifically. Lastly, another important reason for this may be that cultural sustainability aspects typically are of a more vast, diffuse and intangible character and much more difficult both to define and address than many other aspects (Alexander et al., 2020), maybe particularly compared to many environmental sustainability aspects, something which may make it easier to focus on such aspects that are easier both to define and address.

The little focus on cultural sustainability aspects in this study does not necessarily mean, however, that such aspects are not important or even irrelevant for the Norwegian macroalgae aquaculture industry. This was considered supported exactly by the finding that most cultural sustainability aspects seem to be of a (more or less) general character being of similar relevance for many types of companies and industries, and maybe particularly for companies and industries operating just within local communities such as both the salmon and the macroalgae aquaculture industry, and as such aspects were considered important for sustainability of the salmon aquaculture industry by the creators of the WOS-SA, they was therefore considered important for sustainability of the macroalgae aquaculture industry as well. Additionally, the importance of cultural sustainability aspects also for the macroalgae aquaculture industry was considered supported by the fact that a few of the interviewees actually did mention some of such aspects as important, and that no data seemed to indicate that such aspects are not important or irrelevant. Thus, all cultural sustainability aspects of the WOS-SA were included in the WOS-MA. This domain is in other words to a relatively large extent based on the considerations about sustainability made by the creators of the WOS-SA.

5.1.4 Governance

As already described in the results of this study; the governmental sustainability domain encompasses aspects related to how public goods and services are regulated and provided, which means that it includes both how an industry, in this case the macroalgae aquaculture industry, is regulated on a national level, but also the norms and practices initiated on a local and company level. Aspects related to both of these two main types of governance were mentioned relatively frequently among the interviewees interviewed in this study, however, it is both important and interesting to elaborate here that such aspects were typically not initially mentioned as important sustainability aspects in themselves, but as important "solutions", or otherwise ways, to ensure other sustainability aspects. This was found to be particularly the case for assurance of environmental sustainability aspects, where an example of this is that the aspect of the need for knowledge-based and considerate siting of macroalgae aquaculture facilities (emphasised by the subdomain of 'Siting' ('Governance')) was mentioned by several as an essential "solution", or way, to ensure that facilities are placed at locations where the existing environmental conditions are so that the facilities may generate limited negative effects on the surrounding environment. However, good governance was in some cases also mentioned as important "solutions", or otherwise ways, to ensure other sustainability aspects than just environmental sustainability aspects, where an example of this is that the aspect of the need for good collaboration (emphasised particularly by the subdomain of 'Coordination & collaboration about interests & activities' ('Governance')) was mentioned as an essential "solution", or way, to enable productive engagement in R&D to develop technology and knowledge being beneficial for all (emphasised by the subdomain of 'Enquiry & learning' ('Culture')). This supports the general recognition that good governance is of fundamental importance to ensure other sustainability aspects, something which is the reason why the concept of sustainability has been extended into an understanding of the world as one whole complex system consisting of not only three, but four interconnected and interacting subsystems, additionally including the governance system as the fourth subsystem (Sachs, 2015).

Based on the information obtained from the interviewees and the literature, all the governmental sustainability subdomains of the original WOS-SA identified as important for sustainability of the salmon aquaculture industry, were, as the results show, found to be important also for sustainability of the macroalgae aquaculture industry. This reason for this is that even though some of these subdomains, as they are described in the WOS-SA, are relatively specific and not relevant for all types of industries, such as for example the subdomain of 'Siting', they are only specific for aquaculture, and not dependent on the specific type of organism being cultivated, or farmed. Thus, all the governmental sustainability aspects of the WOS-SA were included also in the WOS-MA, without the need for any significant modifications to make them, and the WOS-MA, be specifically applicable to the macroalgae aquaculture industry.

It is important, however, to point out that an essential finding in this study, that is; the finding of the importance of the aspect of 'collaboration', not only between macroalgae companies, but also between macroalgae companies and other industries and actors, actually did indicate a need to make a relatively significant modification of a governmental sustainability subdomain from the original WOS-SA; the subdomain of 'Coordination of interests & activities'. It should be emphasised here that "collaboration with nearby aquaculture facilities and their production" actually already is mentioned as a part of this subdomain in the WOS-SA, and also that "collaboration on behalf of an aquaculture company with the local community, schools, universities or others for research, knowledge-building and dissemination purposes" additionally is mentioned as a part of the subdomain of 'Enquiry & learning' ('Culture') in the WOS-SA. Thus, the aspect of collaboration can be considered as being included as important also for sustainability of the salmon aquaculture industry. However, as collaboration, not only with nearby macroalgae companies, but also with various other industries and actors not only for research, knowledge-building and dissemination purposes, but also for other purposes such as the achievement of resource efficiency, was mentioned by several of the interviewees as of importance for the macroalgae aquaculture industry, it was considered important to broaden both the title and description of this subdomain to ensure inclusion and emphasis on this possibility and importance of such collaboration. This emphasis on the importance of (coordination and) collaboration indicates that, to ensure sustainability of the macroalgae aquaculture industry, it is important to consider this industry in relation to other industries and actors, in addition to be considering it in relation to the environment and the communities in which it operates.

5.1.5 A holistic and complexity-based model for sustainability

This subchapter provides a discussion of the complete WOS-MA as a holistic and complexity-based model of sustainability, largely according to the theories of Peter & Swilling (2014) about how sustainability should be modelled.

The WOS-MA as an integrative model of sustainability

As pointed out in the four subchapters above; it was in this study found that some sustainability aspects, particularly environmental sustainability aspects, were subjects of stronger focus than other sustainability aspects, particularly cultural sustainability aspects. This could indicate that some sustainability aspects are more important than others, something which, on one side, could be recognised as true. Particularly, due to the recognition that the whole Earth system must be kept in the desirable Holocene state to enable further human development and prosperity, and that assurance of environmental sustainability is considered of fundamental importance for this in the current understanding and definition of the concept of sustainability on which the SDGs are based (Griggs et al., 2013; Sachs, 2015), it could be argued that environmental sustainability aspects of the macroalgae aquaculture industry are of particular importance. However, it is also emphasised in this current understanding and definition of sustainability that sustainability is an integrated concept where relevant aspects of all the four main complex systems of the world are of importance to ensure true, holistic sustainability (Griggs et al., 2013; Sachs, 2015). All such relevant aspects should therefore be considered important in the endeavour to understand and ensure sustainability, also of an industry operating in a well-developed country like Norway where some of such relevant aspects may be "taken for granted". This indicates that there should be a stronger focus also on other sustainability aspects of the Norwegian macroalgae aquaculture industry in addition to the strong focus on environmental sustainability aspects, particularly on cultural sustainability aspects. This is further why, in line with the theories of Peter & Swilling (2014), all relevant sustainability aspects that were mentioned by the interviewees, found in the literature, or otherwise identified in this study, were included in the new WOS-MA, and why they are integrated in an heterarchical structure, not specified with any type of importance in relation to other sustainability aspects.

An important potential limitation of the WOS-MA is, however, that the model, through attempting to put a complex reality like sustainable macroalgae aquaculture production into a simplified model like this, is necessarily exactly simplifying this complex reality, and it may with this potentially be missing important interconnections and interactions between all aspects of this complex reality. However, the model is, just like the WOS-SA, designed as to be accommodating this challenge in the best way possible, attempting to reflect these characteristic features of the complex reality. Firstly, this is so in the sense that the different subdomains of the model are designed as to not be mutually exclusive, making the model allow for inclusion of all related aspects of specific topics which may be relevant for several different subdomains of the model. Where this is exemplified for the WOS-SA by the creators of this model through describing how different aspects of the topic of labour aspects are included in three different subdomains of this model (see subchapter 2.5) – an exemplification which is true also for the WOS-MA – this can also be exemplified for the WOS-MA through describing how different aspects of the topic of collaboration aspects are included in (at least) three different subdomains of this model; 'Resource efficiency' ('Environment'), including collaboration specifically about efficient and sustainable use of resources, 'Enquiry & learning' ('Culture') including collaboration specifically about R&D for shared technology-development and knowledge-building, and 'Coordination & collaboration about interests & activities' ('Governance'), a subdomain designed as to be encompassing all aspects of collaboration, but which also is emphasising the need for collaboration specifically to avoid conflicts about areas of the coastal zone.

Secondly, this is so in the sense that, as it can be seen from all the references from one subdomain to others in the operationalisation of all the subdomains of the WOS-MA (see subchapter 4.2), the model is further reflecting interconnections and interactions not only between related aspects of specific topics, but between all included topics and aspects, showing how all components of sustainable macroalgae aquaculture production are components of a larger, integrated whole – and thus, how they can, and should, be seen in relation to each other. This is important to be able to identify and consider not only single negative and positive effects, but also potential negative trade-offs and positive synergies lying in these interactions between all included topics and aspects. This is in turn essential to be able to actually minimise potential negative effects and trade-offs and maximise positive effects and synergies – and thus, to create and maximise shared value for both the industry, and the society and environment, something which is emphasised as of great importance for companies and industries to truly ensure and increase their sustainability (Porter & Kramer, 2006) and to contribute to the SDGs and sustainable development (GRI, UN Global Compact, & WBCSD, 2016).

An example of such a negative trade-off is that breeding of the cultivated macroalgae, with the aim of improving different phenotypic traits such as growth rate, content of one or several desirable compounds, and resistance to biofouling organisms, diseases and pests, on one side is regarded as essential for the macroalgae aquaculture industry to achieve financial profitability (addressed by the subdomain of 'Financial performance' ('Economics')), however, such breeding may on the other side pose a risk of polluting and reducing the genetic diversity of wild macroalgae populations (addressed by the subdomain of 'Biotic effects' ('Environment')). Thus, addressing breeding in such a way that it generates positive effects for financial profitability, but at the same time is not threatening the genetic diversity of wild populations is essential. On the other side, an example of a positive synergy is that development of new technology and industrial processes (addressed by the subdomain of 'Investments in technology & innovation'

(‘Economics’)) can contribute both to reduced costs and achievement of financial profitability for the industry (addressed by the subdomains of ‘Production costs’ and ‘Financial performance’ (‘Economics’)), and also to ensure safe working conditions for employees (as a part of the society) (addressed by the subdomain of ‘Social assurance’ (‘Governance’)), and limited negative effects of such technologies and industrial processes on the environment (addressed by the subdomain of ‘Pollution, emissions & wastes’ (‘Environment’)). This latter example shows that creation and maximisation of positive synergies lying in the interactions between the topics and aspects (addressed by the subdomains) included in the WOS-MA typically may involve creation and maximisation of great benefits, that is; shared value, for both the industry, and the society and environment. Furthermore, the example shows that not only governmental sustainability aspects (see subchapter 5.1.4), but also other sustainability aspects, through these interactions can function as "solutions", or otherwise ways, to ensure other sustainability aspects.

With all this, the WOS-MA, just like the WOS-SA, can be characterised as an integrative model of sustainability, which, in line with the theories of Peter & Swilling (2014), integrates between four main sustainability domains and their pertaining subdomains representing aspects of four main complex systems of the real world considered of importance for understanding and ensuring true, holistic sustainability of the macroalgae aquaculture industry, and reflects the characteristic complex interconnection and interaction between them.

The WOS-MA as a probabilistic, flexible and adaptive model of sustainability
Another important potential limitation of a model like the WOS-MA, attempting to put a complex reality like sustainable macroalgae aquaculture production into a simplified model, is that even though it may manage to include all aspects and their interconnections and interactions that are considered important today, it may not necessarily manage to include all aspects and their interconnections and interactions that are considered important in the future, as the real world, and also the knowledge about it, is continuously changing. However, just like the WOS-SA, the WOS-MA is attempting to accommodate this challenge too, by presenting the domains and subdomains of the model with broad, general descriptions, allowing the model to be able to include additional aspects that are either already existing and also considered important, but were missed in this study, and/or aspects already existing, but not considered important today, and/or aspects that are maybe not discovered or existing yet. For example, as pointed out in the operationalisation of the different subdomains of the model (see subchapter 4.2), the knowledge about many aspects of the macroalgae aquaculture industry, for example potential environmental effects generated by the cultivated macroalgae, is currently relatively limited, but as this knowledge most likely will be increased in the future, there may be many additional aspects other than those identified and presented in this study that are going to be considered important for sustainability of the industry in the future. Due to the broad descriptions, it is, however, a high probability that these aspects too can be included in the model in the future. In this sense, the model can reasonably also be characterised as a probabilistic, flexible and adaptive model of sustainability, which, in line with the theories of Peter & Swilling (2014) about how sustainability should be modelled, is able to accommodate uncertain real-world scenarios and changes as they occur, based on learning.

The WOS-MA as an inclusive model of sustainability

As sustainability is a science of complex systems, and thus, a very comprehensive and complex field of study, it is, further according to the theories of Peter & Swilling (2014), also important that a model of sustainability is developed by use of a multiplicity of perspectives, to capture all relevant aspects of this comprehensive and complex concept and for shared, holistic understanding of it. As the WOS-MA was modified from the WOS-SA by use of a multiplicity of perspectives and information from both scientists, public administrators and actors from different parts of the macroalgae aquaculture industry, it can reasonably also be characterised as such an inclusive model. It is important to elaborate here, however, that the model is not only *developed* by use of perspectives from a multiplicity of different actors; it is also *meant to be used* by such a multiplicity of different actors. For example, it can be used by companies in different parts of the value chain of the industry for example for understanding and support of strategic decision-making to address important sustainability aspects of their production, but it can also be used for example by public administrators and politicians for similar purposes related to the industry. This is important, because there are several aspects of the model that are important to consider to understand and ensure sustainability of the industry, but that are beyond the control and responsibility of the companies themselves to consider, such as for example aspects related to the subdomain of 'Indirect effects economic activity' ('Economics').

5.1.6 Application of the Wheel of Sustainability for macroalgae aquaculture

As a holistic and complexity-based model of sustainability of the macroalgae aquaculture industry meant to be used by a multiplicity of different types of actors, the WOS-MA, just like the WOS-SA, has potential for broad application in the endeavour to ensure sustainable macroalgae aquaculture production.

Firstly, the WOS-MA may function as a kind of *holistic and clear "encyclopedia"* that can be used by a multiplicity of different types of actors *for shared, holistic understanding* of what sustainable macroalgae aquaculture production entails.

Secondly, the WOS-MA may function as *a basis for comparison and assessment* of different types of initiatives meant to contribute to ensure and increase sustainability of the industry, such as for example different types of sustainability standards like the ASC-MSC Seaweed Standard. Based on such comparisons and assessments, potential gaps and overlaps in the content of such initiatives may be identified, and thus, productive improvements can be made.

Thirdly, the WOS-MA may function as *a tool for support of strategic decision-making* by a multiplicity of different types of actors, in the sense that it can be used to identify and consider not only single negative and positive effects of the industry with regards to sustainability, but also potential negative trade-offs and positive synergies lying in the interactions between all the interconnected aspects of sustainable macroalgae aquaculture production. Thus, it can be used to predict and consider potential negative and positive consequences and results of intended practices and policies. This is essential both to ensure that intended practices and policies aimed at ensuring sustenance or progress on some sustainability aspects are not made at the expense of sustenance or progress on other sustainability aspects, and to maximise positive synergies, shared value and this industry's full potential of being a sustainable industry.

5.2 Contributions to the Sustainable Development Goals

By aiming to minimise negative effects and trade-offs and maximise positive effects and synergies being of shared value for both the macroalgae aquaculture industry, and the society and environment, and thus, to ensure true, holistic sustainability of the macroalgae aquaculture industry as it is defined by the WOS-MA, this study shows (see subchapter 4.2) that this industry has the potential to contribute substantially to the SDGs and global sustainable development. The SDGs to which this industry was explicitly identified as to be able to contribute to were SDG 2 ('Zero hunger'), SDG 3 ('Good health and well-being'), SDG 6 ('Clean water and sanitation'), SDG 7 ('Affordable and clean energy'), SDG 8 ('Decent work and economic growth'), SDG 9 ('Industry, innovation and infrastructure'), SDG 12 ('Responsible consumption and production'), SDG 13 ('Climate action'), SDG 14 ('Life below water'), SDG 15 ('Life on land'), SDG 16 ('Peace, justice and strong institutions'), and SDG 17 ('Partnerships for the goals') (United Nations, 2020m). This indicates that the WOS-MA may be a useful tool that can be used for assuring the macroalgae aquaculture industry's contributions to the SDGs and global sustainable development. It is, however, important to point out here that as the SDGs are defining goals and targets for the whole, global world at a macro level, there are several of the goals and targets of these SDGs that are not explicitly relevant for specific companies and industries at a micro level, something which is a reason why not all subdomains of the WOS-MA were shown to have direct relevance for the SDGs.

5.3 Reliability and validity of the study

Reliability and *validity* are key concepts for all types of scientific research, as attention to these concepts typically is essential for making the difference between "poor quality" and "good quality" research. Although both concepts originate from quantitative research, they are essential also in qualitative research – however, as quantitative and qualitative research are quite different types of research, the concepts have somewhat different meanings in these two types of research. Due to this, other terms for reliability and validity are often used in qualitative research (Golafshani, 2003). In this thesis presenting this qualitative study, it is, however, chosen to use the "original" terms. This subchapter provides a discussion of aspects that are considered relevant for these concepts of reliability (subchapter 5.3.1) and validity (subchapter 5.3.2) of the study.

5.3.1 Reliability

In quantitative research, the concept of *reliability* can be shortly summarised as to be referring to the replicability of the methods and the results of a certain study. In qualitative research, which typically produces results from real-world settings and where "the researcher is the research instrument", such a definition of reliability is typically challenging, as real-word settings, including human behaviour, never can be replicated exactly (Golafshani, 2003; Thagaard, 2013). Instead, one important key to ensure reliability as a contribution to "good quality" of a qualitative study is often considered to be to document the steps and methods used in the study, so that it is possible to see how data and results have been generated and how they may have been influenced by various factors (Thagaard, 2013). Such documentation is provided in this thesis through a description of the steps and methods used in this study (see chapter 3), and by attaching the interview guide used for the interviews (see Appendix A). However, it is necessary to discuss some aspects that may have influenced the data and results.

Firstly, it is important to point out that there are several aspects connected to the interviews conducted in study that may have influenced the data, and thus, the results. One such aspect is the questions asked in these interviews. To ensure reliability with regards to the answers to these questions, the questions were, firstly, not sent to the interviewees on before-hand to prevent them from "planning their answers" possibly being influenced by a number of factors, and they were, secondly, planned before the interviews. The latter involved that they were planned to be open-ended and not leading. These open-ended questions allowed the interviewees to talk freely about what aspects they considered important, instead of potentially being influenced by more or less leading questions formulated based on what I, the researcher, knew about the topic from before. However, these open-ended questions, and also the fact that I, due to the semi-structured form of the interviews was free to alter the sequence of the questions and probe for more information in response to the answers from the interviewees, also involved that the answers and the direction and focus of the interviews varied quite a lot from interview to interview – and that this most likely also will happen again if the study is repeated although the same interview guide is being used. This further means that both the data and the following results may not be all the same if the study is repeated.

A related aspect is that I may have influenced the interviewees during the interviews, through, again; the type of questions being asked, but this time with regards to the questions that were not planned, and also through my behaviour. Regarding the former, some of the questions that were not planned, but instead were asked to probe for more information in response to the answers from the interviewees, can be considered somewhat less open-ended than the planned questions, exactly due the fact that they were not planned, but had to be asked spontaneously. I tried to ask neutral questions, but the possibility that I had an influence on the answers due to this is there. Regarding the latter, I also tried to behave as open and neutral as possible, however, it is possible that the interviewees may have been more or less influenced by my behaviour.

To further ensure reliability of the answers from the interviewees, all the interviews conducted in this study were recorded by an audio recorder so that the answers should not become influenced by my reconstruction of them after the interviews, only based on notes. Furthermore, all the recorded interviews were transcribed through verbatim transcription, which means that every word mentioned was written down, instead of starting the interpretation of the data already in this phase by deciding which data to write down. This is considered to be a positive contribution to the reliability of the results.

Even though I have tried to interpret and present the data collected in this study in a neutral way, the presented results of this study will nevertheless be influenced by my interpretation of these data during the review, consideration and coding of them according to the WOS-SA to identify important sustainability aspects of the macroalgae aquaculture industry. This means that these data may have been interpreted and presented differently if another researcher did this review, consideration and coding, and thus, that the results may have been different. This aspect is also largely connected to the validity of the results, which is discussed in the next subchapter.

5.3.2 Validity

In quantitative research, the concept of *validity* concerns whether the research truly measures what it was intended to measure. This is also relevant in qualitative research, although it may be expressed somewhat differently (Golafshani, 2003). In the context of this qualitative study, validity will concern whether important sustainability aspects of the macroalgae aquaculture industry truly were identified, and whether the WOS-MA manages to reflect true, holistic sustainability of this industry. In addition to many of the aspects discussed in subchapters 5.1.1-5.1.5 which are of great importance for this, the following aspects may be of further relevance.

Firstly, an important aspect with regards to validity is whether the methods used are appropriate to achieve the aim of the study (Golafshani, 2003). As described in chapter 3, semi-structured interviews with open-ended questions allowing the interviewees to provide rich, thick descriptions of the aspects that they considered important were considered appropriate for this study as the main method for collection of data about important sustainability aspects of the macroalgae aquaculture industry. This was done because the aim of this study has been to identify, synthesise and develop a kind of theory about important sustainability aspects of the macroalgae aquaculture industry, which is a complex field being relatively unexplored from before, and such a type of qualitative data collection method is valuable exactly when the field of matter is complex and relatively unexplored from before, and exactly to make central contributions to theory development (Doz, 2011). It is therefore considered that this choice of method is a positive contribution to the validity of the results.

The interviews were further conducted with a sample of interviewees which was strategically selected, to ensure that the sample consisted of interviewees who could provide valid answers about important sustainability aspects of the macroalgae aquaculture industry, in the sense of being based on in-depth competence on this industry, and of being representing a multiplicity of different types of actors. This may thus also constitute a positive contribution to the validity of the results. However, an aspect related to these interviewees that may limit the validity of the results, is that the interviewees may not have been completely honest with their answers, for example by not mentioning some important sustainability aspects due to a wish of ensuring their own interests, something which means that the WOS-MA may provide incomplete or incorrect information about such aspects. However, as the sample consisted of a multiplicity of different types of actors with many different types of interests, it is reason to believe that most important aspects were still captured.

As mentioned in the context of reliability in the previous subchapter, my interpretation of the collected data, particularly the data from these interviews, may, however, be an aspect of greater importance with regards to the validity of the WOS-MA. It is possible that I have interpreted (some of) the data incorrectly with regards to what the interviewees actually did mean, and thus, that the WOS-MA is not modelling sustainability of the macroalgae aquaculture industry correctly.

A related important aspect to mention in this context, which further may make the validity of the WOS-MA limited, is that the use of the WOS-SA as a basis for modification to make this model be specifically applicable to the macroalgae aquaculture industry may have influenced my interpretation of the collected data, and thus how this modification was conducted. Most likely, the new model of sustainability of the macroalgae aquaculture industry would not have looked like the WOS-MA if the WOS-SA had not been used as such a basis for modification. However, as the WOS-SA has been developed through thorough work by a number of experienced researchers, and provided many already identified general sustainability aspects that were considered to be just as important for the macroalgae aquaculture industry as for the salmon aquaculture industry because of several general similarities between these two industries, but that would not have been identified without the use of the WOS-SA as such a basis for modification, the use of the WOS-SA in this way is considered more as a quality assurance of the resulting new WOS-MA than as a negative influence.

In addition to the use of the WOS-SA in this way, the use of additional data sources in the form of literature and the ASC-MSC Seaweed Standard besides interviews for collection of data is also considered to be an aspect that most likely has contributed to ensure validity of the WOS-MA. This is so because the use of different data sources helps to get as holistic, complete and correct data as possible (Alexander et al., 2008), and may thus have contributed to ensure validity of the WOS-MA even though I may have interpreted (some of) the data from the interviews incorrectly. However, due to the fact that sustainability is a very comprehensive and complex field of study, and due to time limits for this study, it was difficult to review all possible relevant literature, and it is therefore important to mention that there might be information from these additional data sources that may have been missed in this study.

Lastly, due to time limits, the interviewees, or other experts on the macroalgae aquaculture industry, did not get to validate the WOS-MA before the study was ended. This constitutes a significant limitation to the validity of the model.

6 Conclusions

The aim of this study was to identify important sustainability aspects of the Norwegian macroalgae aquaculture industry, and through this, modify *the Wheel of Sustainability (WOS)*, in this thesis referred to as *the Wheel of Sustainability for salmon aquaculture (WOS-SA)*, to make this model be specifically applicable to the Norwegian macroalgae aquaculture industry. The new, modified version of this model that resulted from this study is named *the Wheel of Sustainability for macroalgae aquaculture (WOS-MA)*.

The results of the study show that all the overarching sustainability aspects in the form of domains and subdomains from the original WOS-SA identified as important for sustainability of the salmon aquaculture industry, except from one subdomain, were found to be relevant also for sustainability of the macroalgae aquaculture industry, and thus, they were included in the new WOS-MA. This shows that there are many similarities between these two related industries with regards to sustainability. However, the results also show that several of the subdomains, primarily the environmental subdomains, nevertheless had to be modified, and some in quite significant ways, to make the new WOS-MA be specifically applicable to the macroalgae aquaculture industry. The main reason for this is that macroalgae and salmon are fundamentally different types of organisms which affect their surrounding environment in several fundamentally different ways. Most importantly, this involves that even though macroalgae aquaculture, just like salmon aquaculture, potentially can generate several negative effects on the environment that must be minimised to ensure environmental sustainability of this industry, macroalgae aquaculture, as opposed to salmon aquaculture, can potentially also generate several positive effects on the environment that can be enhanced to further increase environmental sustainability of this industry. This constitutes a significant difference between these two related industries with regards to sustainability, and indicates that the macroalgae aquaculture industry has an even greater potential to be an environmentally sustainable industry and to contribute to global environmental sustainability than the salmon aquaculture industry. And as assurance of environmental sustainability is of fundamental importance for the aim of keeping the Earth system in the desired Holocene state enabling further human development and prosperity, this is of great importance.

The results of the study do also show that there seems to be a major focus on such environmental sustainability aspects among actors within and connected to the Norwegian macroalgae aquaculture industry, while there is a less focus on some other important sustainability aspects, particularly aspects related to the role and responsibility of companies of the industry as social players in relation to the communities in which they operate – aspects that are mainly addressed by the cultural sustainability domain. Given the need to have a holistic and complexity-based perspective on sustainability, this indicates that there should be a stronger focus also on such other sustainability aspects when dealing with sustainability of this industry.

The new WOS-MA, providing a holistic and complexity-based overview of all identified important sustainability aspects of the macroalgae aquaculture industry, may potentially contribute to a more holistic understanding of sustainability of this industry. It may potentially also function as a tool for support of strategic decision-making, in the sense that it can be used to identify and consider not only single negative and positive effects of the industry with regards to sustainability, but also potential negative trade-offs and positive synergies lying in the interactions between all the interconnected aspects of sustainable macroalgae aquaculture production. Thus, it can be used to predict and consider potential negative and positive consequences and results of intended practices and policies. This is essential both to ensure that intended practices and policies aimed at ensuring sustenance or progress on some sustainability aspects are not made at the expense of sustenance or progress on other sustainability aspects, and to maximise positive effects and synergies to unlock the macroalgae aquaculture industry's full potential of being a sustainable industry. If this is ensured, this industry may contribute substantially to the Sustainable Development Goals (SDGs) and global sustainable development.

However, the knowledge about many sustainability aspects of the macroalgae aquaculture industry is currently relatively limited, and there are not the least several other aspects that make the results and the implications of this study uncertain.
Most importantly, this involves that there is a possibility that (some of) the data about important sustainability aspects of the macroalgae aquaculture industry may have been interpreted incorrectly, and that the WOS-MA have not been validated by the interviewees or other experts on the industry, before the study was ended. Therefore, there is a great need for more research and work to increase the understanding of sustainability of this industry and to ensure the validity of the WOS-MA.

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Appendix

Appendix A: Intervjuguide

1 Introduksjon
→ Kort oppsummering av informasjon om studien og intervjuet, og eventuelle spørsmål.

2 Intervjurespondenten
→ Begynne med noen få spørsmål om intervjurespondenten for å bli litt kjent.

Slik jeg har forstått, så jobber du som [stillingstittel] i [institusjon/bedrift].
2.1) Hvor lenge har du jobbet med dette?
2.2) Hva er bakgrunnen din?
2.3) Kan du fortelle litt om hva du gjør som [stillingstittel] i [institusjon/bedrift]?

3 Makroalgenæringen og bærekraft
3.1) Hva slags aspekter mener du er av betydning, og bør eventuelt adresseres, for å sikre at akvakultur med makroalger skal være en bærekraftig næring?
- *Spesifikke utfordringer for næringen som må unngås/løses?*
- *Spesifikke positive aspekter som bør fremmes?*
- *Mer generelle aspekter/temaer, som gjelder for hele næringslivet generelt?*
- *Miljømessige, sosiale, økonomiske og styrings-/forvaltningsmessige aspekter?*
- *Ulike deler av forsyningskjeden/verdikjeden?*
- *Bedrifts- vs. næringsnivå*?

a.) Til hvert aspekt: Hvorfor mener du at dette aspektet er av betydning?
b.) Til hvert aspekt: Er dette aspektet av samme betydning globalt som i Norge?
- *Hvorfor/hvorfor ikke?*

c.) Til hvert aspekt: Hvordan mener du at dette aspektet bør unngås/løses/fremmes?
- *Hvorfor/hvorfor ikke?*

4 Offentlig regulering vs. privat styring

<u>Offentlig regulering:</u>
→ Hvis <u>ikke nevnt</u> offentlig regulering tidligere:
4.1.a) Hvis vi starter med <u>offentlig regulering</u>; mener du det er viktig med offentlig regulering av akvakultur med makroalger for å bidra til å gjøre denne næringen bærekraftig?
- *Hvorfor/hvorfor ikke?*

4.1.b) I så fall hvilke aspekter mener du bør reguleres av offentlige myndigheter for å bidra til å gjøre makroalgenæringen bærekraftig?
→ *Til hvert aspekt: Hvorfor/hvorfor ikke?*

→ Hvis <u>nevnt</u> offentlig regulering tidligere:
4.1) Er det flere aspekter, utover de vi allerede har snakket om, som du mener bør reguleres av offentlige myndigheter for å bidra til å gjøre makroalgenæringen bærekraftig?
→ *Til hvert aspekt: Hvorfor/hvorfor ikke?*

4.2) Basert på hvilke aspekter du mener bør være offentlige myndigheters ansvar å regulere for å bidra til å gjøre makroalgenæringen bærekraftig; hvordan vil du beskrive den offentlige reguleringen av næringen i Norge slik den er i dag (kort oppsummert)?

- Adresseres de aspektene som bør adresseres?
- Adresseres aspektene på en god måte? Hvorfor/hvorfor ikke (kort oppsummert)?

4.3) Mener du det er behov for endringer i den offentlige reguleringen av makroalgenæringen i Norge fra slik den er i dag, for at den skal bidra til å gjøre denne næringen bærekraftig?

- I så fall hva slags endringer?
- Hvorfor/hvorfor ikke?

Privat styring og private sertifiseringsordninger:

4.4) Når det gjelder de aspektene som du ikke nevnte bør være offentlige myndigheters ansvar å adressere; hvem mener du bør ha ansvaret for å adressere disse i stedet?

→ Til hvert aspekt: Hvorfor/hvorfor ikke?

4.5) Tenker du at disse ikke-offentlige aktørene som du nevnte nå i forrige spørsmål, også bør ha ansvar for å adressere de aspektene som du nevnte tidligere at bør være offentlige myndigheters ansvar? Altså at ikke-offentlige aktører bør ha ansvar utover bare å følge regelverket som er satt av offentlige myndigheter på disse områdene?

→ Til hvert aspekt: Hvorfor/hvorfor ikke?

4.6) Har du noen tanker om hvordan slike ikke-offentlige aktører kan og bør ta ansvar for å adressere disse aspektene på?

→ Til hvert aspekt: Hvorfor/hvorfor ikke?

4.7) Er du kjent med begrepet privat styring? I så fall, hva legger du i det?

4.8) Er du kjent med private sertifiseringsordninger og standarder?
I så fall hva slags kjennskap/erfaringer har du med slike?

4.9.a) Tenker du at bruk av standarder kan være et nødvendig og hensiktsmessig bidrag, ved siden av offentlig regulering, for å gjøre makroalgenæringen i Norge bærekraftig?

- Hvorfor/hvorfor ikke?

4.9.b) I så fall;

a.) På hvilke områder/aspekter mener du det kan være nødvendig og hensiktsmessig med standarder?

b.) Og hva slags type standarder mener du er mest nødvendig og hensiktsmessig på de ulike områdene/aspektene?

→ Til hvert aspekt: Hvorfor/hvorfor ikke?

4.10) Tror du det er hensiktsmessig å ha én standard som adresserer alle disse nevnte områdene/aspektene, eller er det bedre å ha flere ulike standarder som adresserer ulike (kategorier av) områder/aspekter?

- Hvorfor/hvorfor ikke?

4.11) Hva mener/tror du må til for at private sertifiseringsordninger og tilhørende standarder skal bli tatt i bruk og fungere på en hensiktsmessig måte, i Norge først og fremst?

5 «The ASC-MSC Seaweed Standard»

5.1) Har du noe kjennskap og/eller erfaringer med denne standarden?
I så fall hva slags kjennskap/erfaringer?

→ Hvis ja:

5.2) Hva er din generelle oppfatning av denne standarden (kort oppsummert)?

5.3) Når det gjelder selve aspektene som adresseres i denne standarden; syns du disse er relevante, i forhold til hva du mener bør adresseres av en privat standard for å gjøre makroalgenæringen i Norge bærekraftig?

- *Hva slags aspekter mener du er på plass i standarden, som bør adresseres av den?*
    - *Hvorfor?*
- *Hva slags aspekter mener du eventuelt mangler, som bør adresseres av den?*
    - *Hvorfor?*
- *Hva slags aspekter mener du eventuelt bør fjernes, som ikke bør adresseres av den?*
    - *Hvorfor?*
    - *Bør disse aspektene evt. adresseres av andre? Hvem? Offentlig regulering?*

5.4) Basert på det vi har snakket om til nå; mener du at denne standarden er hensiktsmessig å anvende for makroalgenæringen i Norge, slik den ser ut nå?

- *Hvorfor/hvorfor ikke?*
- *Hva slags endringer mener du evt. må til for at den skal bli hensiktsmessig å anvende for makroalgenæringen i Norge?*

6 Avslutning

6.1) Hovedfokus i dette intervjuet har vært å innhente informasjon og perspektiver om hva som er viktig for at akvakultur med makroalger skal være en bærekraftig næring, og om hvordan offentlig og privat regulering kan bidra gjennom å adressere disse. Er det noe mer du vil tilføye i denne sammenhengen?

6.2) Kan jeg evt. kontakte deg igjen hvis jeg ser at jeg kunne trengt å stille noen ytterligere oppfølgingsspørsmål?

6.3) Er det noe du lurer på før vi avslutter?

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Operationalisation of sustainability of the Norwegian macroalgae aquaculture industry

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