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Sustainable fishing fleet

A systems engineering approach

Thesis for the degree of philosophiae doctor

Trondheim, September 2007

Norwegian University of
Science and Technology
Faculty of Engineering Science and Technology
Department of Production and Quality Engineering



NTNU
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Preface

Development of more eco-efficient products was my main interest when I got my Master's degree in Product Design Engineering at the Norwegian University of Science and Technology in 2004. I had little knowledge of the Norwegian fisheries and the fishing fleet when I started my Ph.D. work, but sustainability in general was an issue that attracted me. Looking at the complexity of the fisheries and the wide variety of fishing vessels, I realized that making a contribution to increased sustainability in the fisheries would be a challenging task. However, when I came to see my Ph.D. thesis as a "product" to be developed, my background gave me some clues on how to complete my work.

I have to say that this thesis has led me into fields of expertise that had so far been quite unknown to me. I have investigated strategies from fields ranging from marine eco-systems, fishing vessel technology, fisheries management, system analysis, decision theory, risk management, and economics. The challenge was to combine the theories of these fields with my knowledge of product development, and apply it to the task of the thesis. As such, I have felt that my work deviates quite a bit from the conventional doctoral thesis, because it has a wider profile. Even though the work has been quite demanding, it has definitely been very interesting and fun.

The work has been carried out from 2004-2007 at the Norwegian University of Science and Technology (NTNU), Department of Production and Quality Engineering, and SINTEF Fisheries and Aquaculture. The Ph.D. has been funded by the Norwegian Research Council and the Norwegian Federation of Fishing and Aquaculture Industries Research Fund (FHF). The thesis is part of the strategic institute program "Sustainable vessel technology and fleet structure" at Sintef Fisheries and Aquaculture.

I have to express my sincere gratitude to my advisor, Professor Marvin Rausand at Department of Production and Quality Engineering (NTNU), for his perfect amount of guidance and encouragement. If I ever get to supervise a Ph.D. student, he will serve as my role model. I am also grateful to Dag Standal, Senior Researcher at Sintef Fisheries and Aquaculture, for helping me understand the nature of the Norwegian fisheries and fisheries management.

Finally, I would like to thank Professor Jørn Vatn at Department of Production and Quality Engineering and Professor Harald Ellingsen at Department of Marine Technology for valuable input to my thesis, and my colleagues at SINTEF Fisheries and Aquaculture and NTNU for providing the pleasant social environment for my work.

Trondheim, September 2007

Ingrid Bouwer Utne

“As for me, all I know is I know nothing”
(Sokrates, *Phaedrus*, sec. 235)

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Summary

Many fisheries have significant challenges related to sustainable development, such as overexploitation and overcapacity in the fishing fleet. Overcapacity leads to increased pressure on fish resources, reduced profitability, and environmental problems such as greenhouse gas (GHG) emissions and acidification from fuel consumption. Sustainable management of the fish resources is an important objective in Norway, but overcapacity is a problem in several Norwegian fleet segments. Important issues in this respect are whether the traditional management models are able to deal with the capacity development, and whether the role of technology as a relevant discipline in fisheries management is underestimated.

The objective of this work has been to integrate a technological perspective into fisheries management in order to improve sustainability in the fishing fleet. The thesis work has been limited to the Norwegian fisheries in Norwegian territorial waters. Since the main problems addressed in this thesis are sustainability and overcapacity, the system boundaries are limited to the fishing fleet. This means that the marine ecosystem in where the fishing vessels are interacting, is outside the thesis' boundaries.

The main contributions of this thesis are:

- Development of a methodological framework that structures fisheries management decision-making, with main emphasis on improved sustainability in the fishing fleet.
- Clarification of the concept of sustainability in the Norwegian fishing fleet.
- Classification of attributes characterizing sustainability, and a performance evaluation of the different vessel groups in the cod-fishing fleet.
- Comparison of two cod-production systems, with focus on sustainability.
- Suggestions for how fisheries management can evaluate sustainability on a regular basis.
- Improved foundation for further research about sustainability in the fisheries. A lot of literature is collected and synthesized.

The framework developed is based on the systems engineering process. The nature of sustainability requires a systems perspective. There are different system

analysis methods, but from a technological perspective, dealing with multidisciplinary tasks, systems engineering has been selected as the most feasible process. It has a strong focus on stakeholder needs and requirements, and it facilitates frequent evaluations of sustainability, which is important in order to assess management efficiency and goal achievement.

Problems regarding sustainability in the fisheries are not only caused by technological development, but have organizational challenges as well. However, in this thesis the focus is within the technological perspective. Systems engineering is not applied as an attempt to change the structure of fisheries management, but as means of suggesting a decision-making process that improves sustainability in the fishing fleet.

Fisheries management involves decision-making in situations often characterized by high risks and uncertainties, and it may be difficult to predict the outcomes of the decisions, for example, regarding sustainability in the fishing fleet. A number of tools that are available to support decision-making have been discussed and used in the thesis, such as cost-benefit analysis, risk acceptance criteria, life cycle cost (LCC), the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD). Nevertheless, these tools do not provide “correct” answers; they have limitations, they are based on a number of assumptions, and their uses are based on scientific knowledge as well as value judgments involving political, strategic, and ethical issues. This means that these methods leave the decision-makers to apply decision processes outside the practical applications of the analyses, to which the framework offers guiding principles and structure.

The main outcome of using systems engineering principles in fisheries management, is that the framework offers a broader analytical perspective to fisheries management and sustainability, which acknowledge that sustainability cannot be distinguished from the context. Today, most input to fisheries management come from biology and economy, such as stock assessments and profitability analyses. In systems engineering, information from different scientific disciplines, for example, biology, social sciences, economy, and technology, are necessary input to the analyses and decision processes, because fisheries management is much more than bio-economics. Application of the systems engineering process in fisheries management, and the inclusion of technology, introduce new perspectives, new disciplines, and new stakeholders into the decision-making process in the fisheries.

Based on the framework developed in the thesis, the sustainability performance of the cod-fishing fleet has been evaluated. Sustainability in the fishing fleet may be characterized by seven attributes; accident risk, employment, profitability, quality, catch capacity, bycatch/selection, and GHG emissions/acidification. Indicators have been identified in order to measure the system performance within the attributes. The evaluation shows that there are differences in the performance of the vessel groups. These differences pose a major challenge to fisheries management in their decision-making regarding sustainability in the fleet. The smallest vessels have the lowest fuel consumption (kg fuel/kg fish), but they have a very high accident risk (FAR). The evaluation of cod fishing vs. cod farming

shows that the potential growth in the cod farming industry may cause changes in the management system of the cod fisheries, such as a possible shift from the IVQ-system of today to an ITQ-system.

The Norwegian fisheries management lacks frequent evaluations of its policies, and the information and data available about the fisheries are fragmented. Sustainability should be evaluated on a regular basis by use of performance indicators to determine if sustainability increases or decreases. For simplicity, the indicators could be aggregated into a sustainability index showing the overall system performance. Aggregation implies simplification and weighting of the indicators, which means that such an index should be used with care. Sustainability implies a long term perspective when taking decisions, because future generations will be affected. The performance evaluations can give indications of trends, which means that the results can be used to predict consequences in the future, based on the current development.

Structure of thesis

This thesis is divided into two parts:

- Part I consists of an introduction to the topics covered by the thesis, a description of the research methods applied and the main results. This part combines the content of the publications found in Part II into a totality that serves to fulfill the thesis' objectives.
- Part II consists of the publications constituting the major work carried out.

2.1 List of publications

This thesis includes the following publications:

- Article 1:
Systems engineering principles in fisheries management. *Marine Policy*, 2006, 30, p. 624-634.
- Article 2:
System evaluation of sustainability in the Norwegian cod-fisheries. *Marine Policy*, 2007, 31, p. 390-401.
- Article 3:
Are the smallest vessels the most sustainable? Trade-off analysis of sustainability attributes. Accepted for publication, *Marine Policy*.
- Article 4:
Can cod farming affect cod-fishing? A system evaluation of sustainability. *Marine Policy*, 2007, 31, p. 527-534
- Article 5:
Life cycle cost (LCC) as a tool for improving sustainability in the Norwegian

fishing fleet. Submitted, Journal of Cleaner Production.

- Article 6:
Acceptable sustainability in the fishing fleet. Accepted for publication, Marine Policy.
- Article 7:
Improving the environmental performance of the fishing fleet by use of Quality Function Deployment (QFD). Submitted, Journal of Cleaner Production.
- Article 8:
Risk in fisheries management: From rule-based to function-based management in Norway? IIFET 2006 Proceedings
- Article 9:
System performance evaluation of the Norwegian cod-fishing fleet. To appear, NFTC 2006 Proceedings

Part I

Main Report

Introduction

The title of this thesis “Sustainable fishing fleet. A systems engineering approach” indicates two major topics: Sustainability and the fishing fleet. Sustainability in the fisheries comprises ecological, economic, and social dimensions, dimensions that are influencing the fishing fleet. Technology can be looked upon as an agent to achieve sustainability within these dimensions. For instance, the environmental burdens can be substantially reduced by choosing the right technologies [1].

Sustainable development, as defined in “Our common future”, the 1987 report from The World Commission on Environment and Development [2], is a question about social justice in time and space. Human welfare is the main objective, and detrimental effects are seen as threats to sustainability. In the thesis context, the concept of sustainability implies technological development within the framework of an environmentally sound administration of fisheries resources, but also increased efficiency for the individual actor and for the industry as a whole.

Even though there is a growing focus on sustainable development in the fisheries, both at a global and local scale, many fisheries face fundamental problems, such as overexploitation and overcapacity in the fishing fleet [3, 4]. Overcapacity leads to increased pressure on fish resources, reduced profitability, and environmental problems such as greenhouse gas (GHG) emissions and acidification from fuel consumption. Sustainable management of the fish resources is an important objective in Norway [5], but overcapacity is a problem in several Norwegian fleet segments [4].

The technological developments adopted by the Norwegian fishing fleet after World War II, such as automatic hauling of purse seine in pelagic fisheries, modern stern trawling, and automatic baiting in line fishing, have led to increased catch capacity. Introduction of modern resource management measures, such as total allowable catch (TAC), vessel quotas (VQ), limited access, and structural measures to reduce the number of fishers and vessels to increase profitability, have not solved the problem of overcapacity [6, 7]. Analyses of the technical capacity development in the Norwegian fishing fleet [7, 8] show that there is an overall capacity increase even though the number of vessels has been reduced.

A reduction of overcapacity is one step towards sustainable fisheries [4]. Important issues in this respect are whether the traditional management models are able to deal with the capacity development, and whether the role of technology as a relevant discipline in fisheries management is underestimated. The problem of overcapacity indicates a need for a stronger integration of technological perspectives into fisheries management. In such a context, there is need for improved tools and more knowledge that visualize the consequences of external conditions and technology choices, so that stakeholders in industry and public administration are able to make sustainable decisions. The overcapacity in the fishing fleet has made it necessary to construct new analytical models in order to find out more about framework conditions and technological development in the fleet with respect to sustainability.

The main contribution of this doctoral thesis is a framework based on the systems engineering process, to be used by fisheries management (and other stakeholders to the fisheries) as means to improve sustainability in the fishing fleet. The framework structures the decision-making process, due to a strong focus on stakeholder needs and requirements, and it facilitates frequent evaluations of sustainability, which is important in order to assess management efficiency and goal achievement.

The first part of the thesis gives an introduction to the concept of sustainable development, the Norwegian fisheries and fishing fleet, and the problem of overcapacity. The background is thoroughly described because of the complex and multidisciplinary nature of the fisheries and the thesis. The articles discuss important issues and results, but the background chapter is meant to put the topics in the articles into a larger context. Those readers familiar with these topics may start reading from, Sect. 3.1.6. Thereafter, objectives, delimitations, the research approach, methods, main results, and conclusions are described. The articles are included in part two.

3.1 Background

3.1.1 The concept of sustainable development

The ongoing environmental debate seems to believe that environmental concern is a problem of the industrial society that has evolved after the industrial revolution. But within archaeological research, there is a growing consensus that ancient societies may have collapsed due to environmental degradation. Also ecological factors have been one of the most important driving forces behind every social transformation known in history. The difference between the past and the present is that the global economy has shown incredible growth the last few decades, a growth which has caused a tremendous change in human life in a very short time period [9].

The report "Our Common Future" [2] can be looked upon as the starting point for most of the current discussions about the concept of sustainable development.

Nevertheless, the concept can be traced further back in time. Views of nature can be found in different religions. Whereas several people have found Judaism and Christianity to be an essential source of the environmental crisis by spreading thoughts about man's right to "rule over the fish of the sea and the birds of the air and over every living creature that moves on the ground" [10], others conclude that religions have little responsibility for environmental degradation. In some societies, there have been and to a certain degree still are, traditions for viewing the nature alive in the same way as humans. The core element is the beliefs of human beings living in harmony with nature [9].

Thomas Robert Malthus (1766- 1834) was the first economist to see the problems with an increasing population and limitations of resources. He described problems of feeding an exponentially growing human population [6]. As the population grew, diminishing returns would reduce the food supply available. The standard of living would sink and the population would then stop growing. Malthus described environmental limits which can be seen as a pre-version of the concept of sustainable development [9].

The first UN environmental conference took place in Stockholm in 1972 (The United Nations Conference on the Human Environment). The conference represents a major step forward in the development of the concept of sustainable development. The main outcome of the conference was the United Nations Environmental Programme (UNEP) which coordinates the international effort within environmental protection [11]. Even though there were no strong links between environment and development, it became clear that the path of economic development at that time had to be changed [9]. Whereas the industrialized countries focused on environmental problems, the development countries were more occupied with poverty issues. Later, this polarization has created problems in negotiations between the rich and the poor countries [11].

The terms "environment" and "development" became closer linked in the years after the Stockholm conference. Terminology like "environment and development", "environmentally sound development" and "eco-development" evolved. The first major breakthrough came in 1980 with the World Conservation strategy with subtitle "Living Resource Conservation for Sustainable Development". This strategy was developed within the International Union for the Conservation of Nature (IUCN), working together with the World Wildlife Fund for Nature and UNEP. This was the first major attempt to integrate environment and development [9].

The World Commission on Environment and Development (WCED) was established (1984-1987) in order to explain the relationship between poverty, environment and development. The commission, also called the Brundtland commission, picked up the concept of sustainable development and made it commonly used. The report "Our Common Future" [2] defined sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The report recommended a global UN conference in order to compose a universal declaration and convention on sustainable development; the United Nations Conference on Environment and Development, UNCED.

The preparation of UNCED was influenced by the different perspectives between the industrialized countries and the development countries. The G77 countries (G77 was established in 1964 in opposition to G7) did not want to participate at the conference unless the industrialized countries committed to transference of financial resources and technology to enable sustainable development. The main part of the industrialized countries gave in to several of G77's arguments.

UNCED was arranged in Rio, Brazil, in 1992. 27 fundamental principles, known as the Rio Declaration, were produced. Years of discussion and debate culminated in this document in which "Sustainable development" plays an important role. The Rio Summit was a landmark event putting the environmental challenges in focus of the world community [12]. The UNCED gathered delegates from 178 countries. The main themes for the negotiations were issues concerning the atmosphere, biotechnology, international institutions, legal issues and financing, transfer of technology, fresh water, and forests. Three documents were drawn; the Agenda 21, the Rio Declaration and the Forest Principles. The Convention on Biodiversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC) were also finalized and signed.

Agenda 21 discusses human environmental issues such as poverty, human health, population development, and consumption patterns, natural resource issues like biological diversity, management of forests and coastal areas etc., and puts attention to participation at all levels in the population. The Rio Declaration's fundamental principles are meant to work as guidelines for future development. The principles state human rights regarding development, and a common responsibility for protecting the environment. The CBD came about as a result of the observed reduction in biological diversity caused by human activities. The UNFCCC states that human activities emit large amounts of gases into the atmosphere which contribute to the greenhouse effect. Thus, the industrialized countries have a distinct responsibility to reduce its emissions.

The Kyoto Protocol (1997) is part of UNFCCC, and is an important step to reduce CO_2 emissions into the atmosphere. The protocol came into force Feb. 16th 2005 as a result of ratification by several industrialized countries that altogether emit 55 % of the total gas emissions. The assigned sizes of the different countries' quotas vary from 92 to 110 % of emissions in 1990. According to the Protocol, Norway's total emission quota is 1% higher than the 1990 level in the period 2008-2012 [13].

The UN Commission on Sustainable Development (CSD) was established in order to follow up the commitments made by participating countries during UNCED. CSD is responsible for making reports on countries' effort within sustainable development. CSD has been criticized for being ineffective, while others mean that the Commission plays an important role in keeping issues related to sustainable development on the agenda.

Rio +5 (UNGASS 1997) was a UN conference held in New York as a follow up of the Rio Conference. 53 state leaders and other delegates discussed the countries' work with Agenda 21. The results showed that the intentions from the UNCED were not being realized, although there was some progress. The gap between the

rich and the poor had increased and so had the level of green house gas emissions. One of the major changes that came out of UNGASS was the possibility for Non-Governmental Organizations (NGO) to speak to the UN General Assembly, in accordance with the Agenda 21.

The World Summit on Sustainable Development in Johannesburg in 2002 (Rio + 10) gathered 65 000 delegates to plan achievements within sustainable development based on the results and challenges of the process that followed the Rio Summit. The summit meeting was no success. The negotiations resulted in few political commitments, although there was progress compared to UNGASS. A political declaration and a brief plan were worked out. The plan discussed important obligations related to the preservation of biological diversity, sustainable management of the fish resources, access to fresh water and the sanitary conditions for the poor part of the world's population. Difficult issues about globalization, the connection between trade and environmental care, and the industrial countries' use of agricultural subsidies were discussed; controversial issues that were put aside before the Rio Conference [11].

Since "Our Common Future" was published, a large amount of definitions and interpretations linked to the concepts of sustainability and sustainable development, have arisen. Most often the interpretations are influenced by beliefs of the institutions or groups behind. Thus, it is difficult to establish a definition that captures all perspectives. Sustainability has become a word that can mean almost anything. This might be the greatest danger; that the word becomes a cliché and then loses its influence on keeping environmental protection on the agenda [14].

The most well-known definition of sustainable development is, as mentioned previously, the one of WCED [2]: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

In order to operationalize the concept of sustainable development, it is necessary to look closer at the definition given above. The first key concept is the meaning of "need". Is "need" related to basic needs or every type of consumption [15]? The report of WCED describes further: "The concept of "needs", in particular the essential needs of the world's poor, to which overriding priority should be given". Basic needs are related to needs for employment, food, energy, water and sanitation. Thus, main priority is to be given to the poor part of the world. Still, it may be unrealistic to think that it is possible to meet the basic needs of the poor unless the rich reduce their living standards. This is a controversial issue, though [16].

Another key concept of the WCED definition is: "The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs". This links reduction of poverty, environmental improvement, and social equitability to sustainable economic growth [9]. According to the WCED-report, sustainable development requires high economic growth rates in developing countries and moderate to low growth rates in developed countries. But sustainable development also requires a change in the content of growth, to make it less material- and energy-intensive and more equitable in its impact. Ecological problems caused by exploitation of natural resources

have to be taken into consideration, and maintenance has to be prioritized. This means that economic growth cannot be the only priority at the sacrifice of the environment. A lot of criticism has been raised on the possible contradiction between the drive towards higher profits and sustainability. Also, the WCED-report is academically weak as it contains examples, but no critical evaluation of possibilities for sustainable growth in a broader sense [17].

WCED states the necessity of sustainable growth. To achieve sustainable development without growth, means that the world population resources must be redistributed, which is probably not likely [16]. A lot of the debate around the WCED report has questioned the combination of achieving sustainable development and growth at the same time. This debate has two related dimensions; nature's carrying capacity and the relationship between this capacity and human needs. "Carrying capacity" is according to the World Business Council on Sustainable Development (WBCSD) the ability of the earth to carry withdrawal and displacement of materials [18]. Nature's carrying capacity may be measured empirically. The relationship between human needs and the carrying capacity is more complicated. WCED [2] writes (p. 44): "Living standards that go beyond the basic minimum are sustainable only if consumption standards everywhere have regard for long-term sustainability. Yet many of us live beyond the world's ecological means, for instance in our patterns of energy use. Perceived needs are socially and culturally determined, and sustainable development requires the promotion of values that encourage consumption standards that are within the bounds of the ecological possible and to which all can reasonably aspire".

Membratu [9] categorizes the variety of definitions of sustainable development into three major groups:

1. The Institutional Version
2. The Ideological Version
3. The Academic Version

Examples of institutional definitions are given by WCED, the International Institute of Environment and Development (IIEE), and the World Business Council for Sustainable Development (WBCSD). They are based on the need satisfaction, but have different interpretations dependent on their interests [19].

Environmental versions of classic ideologies, such as liberation theology, radical feminism, and Marxism are the dominant ones at the ideological level. The liberation theology (Eco-Theology) holds disrespect to divinity as the source of the environmental crisis, radical feminism (Eco-Feminism) blames the male domination of nature and of women, where as Marxism (Eco-Socialism) blames Capitalism.

The academic version can be divided into economist, ecologist, and sociologist conceptualizations. The environmental economists claims that the environment is undervalued since it is free of charge; thus it becomes overexploited. If the environment was highly valued as a commodity, the market would protect it better. There are different opinions within ecological concepts, but the deep ecologists view humanity just as important as everything else on the planet; no more,

no less. Socialist conceptualizations are based on rethinking of the social hierarchy.

The different interpretations of sustainability have resulted in a narrow picture instead of catching the whole picture. This thesis concentrates about sustainability regarding the fishing fleet. Sustainable development is a principle of justice between generations. In the fisheries this implies that the resources, the fish stocks, flora and fauna, and clean sea and coastal lines ought to be accessible to future generations the same way as it is now [20].

3.1.2 The Norwegian fisheries

The Norwegian coastal areas are among the world's most productive, and the possibilities for fishing were probably the reason for the early settlement. Today, being one of the world's largest exporters of seafood, about 90% of all Norwegian seafood is exported, and in 2005 the total value was NOK 31,7 billion [21, 22]. Thus, the fisheries are important to maintain settlement in the coastal areas.

Fish trade and cargo along the Norwegian coast started in 1000 A.C. In the 12th century, stock fish and herring were transported to England, and remained Norway's most important export commodity for centuries. At the end of the 13th century, the Hanseatics controlled the stock fish trade from northern Norway, where the largest fish resources could be found. In the 19th century, the seasonal fishing in Lofoten (Figure 3.1) and Finnmark started. The spring herring fishery in the south-western part of Norway gave incredible catches [23].



Fig. 3.1. Lofot fishery, Skrei 2007. Permission by the Norwegian Seafood Export Council. Photographer: Kjell Ove Storvik.

At the end of the 1800's, the fishery business was overcrowded and the prices went down. The crisis drove the technological developments forward. The vessels became larger, and new, effective catching methods like chain nets and purse seines were introduced. In the beginning of the 20th century, the fishing fleet was motorized. The next decades, new technology, such as echo sounders, purse seines, and trawl, made the fishing fleet so effective that overexploitation became a problem [23].

After World War 2, there was a period of high growth in the world fisheries. Between 1950 and 1970 there was an annual catch increase of 7%, but the high growth could not last forever. The technological developments led to overexploitation of the fish stocks. Technological change and lack of monitoring and control were, for example, some of the causes to the serious collapse of the Northern cod stock off the coast of Newfoundland in the early 1990's [24]. Until the 1960s, there was no regulation of the Norwegian fisheries. From 1960 to 1990 there has been a major change from open access fisheries to public regulation by the government [25].

3.1.3 Fisheries management

The perception that land is owned and the sea is free has persisted in many societies for centuries. The fishers were free to go wherever they liked to go. In many places there existed some kind of an ownership, but only a few miles from land. The "freedom of the sea" had a powerful influence on the development of the fisheries, and was formalized in the 16-17th centuries when the major fishing powers decided to solve conflicts over trade routes by allowing multinational access [6].

As fisheries became more intensive; a result of growth in the human population, there was increased conflict about the fisheries. In the 15th century, several countries claimed exclusive rights to inshore waters. The 1930 Hague Conference on the Codification of International Law decided that the claims to territorial seas were acceptable, but it did not suggest their sizes. By 1972, 66 countries had a 12-mile limit. But countries with important fishing interests were not satisfied. As early as in 1947, Chile and Peru had claimed 200-mile jurisdiction. Nevertheless, it was the 1973 UN Conference on the Law of the Sea that formalized the 200-mile limits, bringing 90% of the fisheries under national control [6]. The coastal states are committed to manage the resources in a sustainable way [26, 27].

The "tragedy of the commons" [28] describes a situation where many participants (fishers) feel that what they do today has no consequence for what they gain tomorrow. This means that open-access fisheries will be exploited beyond their biological limits, because each fisher wants the most of the resource today as the fish that remains in the sea is available for someone else to catch [6]. Bio-economic models, such as the one in Figure 3.2, help explain overexploitation, the need for closing of the commons, and effects of management measures [29].

Figure 3.2 shows the costs and revenues for commercial fishing. The fish prices are assumed constant, which means that the total revenue is proportional to the

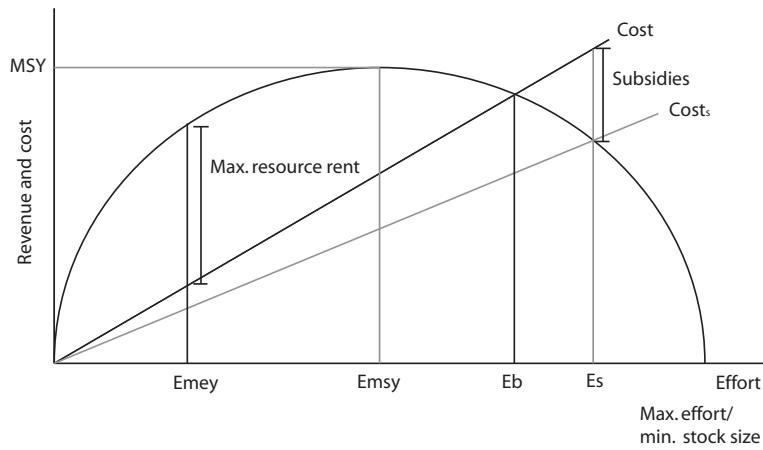


Fig. 3.2. The Gordon-Schaefer model. Theoretical and simplified long term cost-revenue curves for commercial fishing visualizing the resource rent [6, 25, 29].

catch, following the curve of surplus production (Figure 3.3). Maximum Sustainable Yield (MSY) is the largest catch that can be caught without causing the stock to collapse [6].

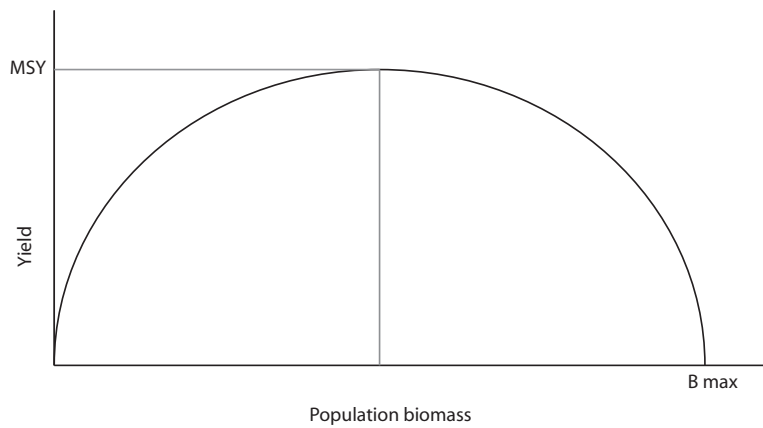


Fig. 3.3. The Maximum Sustainable Yield (MSY) [6, 25].

In open-access fisheries, the fishers will invest in new vessels as long as the catch value gained from a new vessel in, for example one year, is higher than the total costs in that same time period. A long term equilibrium between catch and stock surplus production, means equalizing the value of catch per unit effort to the cost per unit effort, E_b in Figure 3.2, where C is the cost curve. The difference

between the revenue and the cost curve is the resource rent. The highest resource rent is found in *Emey*.

Adaptation of the fishing fleet to fluctuating fish stocks takes time, and the costs may in some time periods be higher than the revenue. Such a time period may be extended when the fishers, waiting for improvement in the resource situation, decide to continue their operation. Then the fishers will not gain a normal yield without subsidies. Subsidies create an artificial equilibrium, illustrated by a change in the cost curve, C_s .

After World War II, the main concern in the fisheries was profitability, and not overexploitation of the fish stocks. In the 1960s and 1970s, the need for a resource management system increased due to visible signs of too much pressure on fish stocks, for example in the herring fishery. At the same time in the rest of the western world, there was a "green wave" focusing on shortage of food, environmental problems, and overexploitation of natural resources. "The tragedy of the commons" [28] considers the fishers to be "economic men", which is a disputed issue [29,30]. Nevertheless, the closing of the Norwegian commons are closely related to Hardin's article [28] and bioeconomy, such as the Gordon-Schaefer model, which is the basis for the fishery economic analyses carried out today [30].

The main bodies of the Norwegian fisheries management consist of the Ministry of Fisheries - and Coastal Affairs and the Directorate of Fisheries. The Ministry carries out administrative tasks through legislative and regulatory work. The Directorate serves as the Ministry's advisory and executive body, and its main tasks involve regulation, guidance, supervision, resource management and quality control [31].

Norway has bilateral and multilateral agreements. Negotiations with several countries are carried out every year. In the Barents Sea, Norway cooperates with Russia, in the North Sea there is cooperation between Norway and the EU about management of seven fish stocks. Several stocks wander between the economic zones and international waters. The management of the international areas are difficult as there are few effective control measures. Norway works within the North- Eastern Fisheries Commission (NEAFC) and the North- Atlantic Fisheries Organization (NAFO) to put restrictions to fishing in the unregulated areas. Norwegian fishing vessels operating outside the Norwegian jurisdictional district are regulated [26].

Management actions can be divided into catch controls, effort controls and technical measures. Catch controls are also known as output controls. Output controls intend to limit the weight of catch, to reduce fish mortality, and include total allowable catches (TAC) or quotas (Q), individual quotas (IQ) and vessel catch limits. Often, catch control really works as landing control. Fishers may kill and discard unseen large numbers of fish of a size or quality that does not attract the highest prices, a process known as high-grading. Thus, the total catch may be higher than the catch landed [6].

TAC encourages fishers to race for fish because the resource is common property and everybody wants their share of the total catch. When the total catch is caught, the fishery is closed, which results in shorter fishing seasons, reduced fish

quality, higher by-catch, and more dangerous working conditions for the fishers. TAC also encourages overcapacity since larger and powerful vessels catch the fish more effectively. The processors have to deal with varying supply of fish; they invest in expensive processing equipment, but since its capacity is only fully utilized in periods, the processing and marketing costs increase [6].

The IQs add up to the TAC. IQs allow fishers to catch their quota at a pace they like because they do not have to compete for their share. IQs increase the economic benefits as the catch quality usually improves, the supply to processors and markets is more stable, and improved safety for the fishers results from deciding when and how they want to catch their quota. However, IQs are usually allocated based on the fisher's activity the previous years, and most often the fishers want the largest proportion of the TAC they can get. Thus, the enforcement of the IQs has to be effective; otherwise there will be a competition among the fishers to fish. The system with IQs works better with few large vessels landing catches in major ports than hundreds of fishers who sell their catches to local markets [6].

Individual transferable quotas (ITQ) allow fishers to trade their quotas, which means that the fishers benefit when selling their quota. Usually the most efficient fishers buy ITQ from the less efficient ones. Operating costs and fleet capacity decrease and profitability increases. The number of employees sinks, but the remaining fishers earn more money. In some cultures ITQs are unacceptable [6].

Taxes can be a way of controlling the catch. Other natural resources, such as oil and gas, are taxed. Overcapacity may develop when the fishers do not have to pay to fish even though fish is scarce. A tax on the fish landings would increase the costs so that the revenues would have to be higher for the fishing to be profitable. The biggest problem with taxes is the fluctuations of the fish stocks and that the tax system has to be adjusted accordingly [6].

Effort controls (input controls) limit the number of vessels or fishers who work in a fishery, the amount, size and type of gear to be used, and the time the gear can be in the water. Effort controls may also put restrictions to the size and the power of vessels and the periods when they fish. Effort control measures aim to reduce fishing mortality by limiting the fishers' catch ability. There are different types of effort controls; licenses, individual effort quotas (IEQ) and vessel or gear restrictions. Licenses restrict the number of vessels or fishers in the fishery, and they may be transferable. IEQ limits the time of working by a type of gear, a vessel or a fisher, which means that the fisher may only catch fish a given number of days in a year or that it is only allowed to set a certain number of pots. The vessel and gear restrictions may control the size and design of pots or nets or the size of the vessel etc [6].

The initial allocation of licenses may be a problem if the aim is to reduce the fishing effort. If this is not possible, every fisher may have a license which is not renewed when the fishers leave. A stronger measure can be to buy back licenses. The licenses do not reduce fishing mortality as the remaining fishers compete for the fish. License regulations are quite easy to enforce, but the costs may be high. If IEQ is used to control fishing, also the number of fishers and vessels has to be limited. Otherwise, there is little effect in the effort control restrictions [6].

A process called technological creep happens as fishers adjust their gears, vessels and behavior to compensate for the loss of catch when effort control restrictions are imposed. The technological creep leads to little reduction of fishing mortality, and therefore the form of effort control should not give the fishers the scope to do these kinds of modifications [6]. Gear and vessel restrictions often stop fishers from using the gears that would be most effective, which may increase costs. Limitations to vessel size may contribute to smaller, but more powerful vessels. Thus, risk may increase as fishers go further out to sea in smaller vessels. Effort control is usually easier to control than catch control, but effort control rarely has the desired consequences. Thus, effort controls have to be imposed together with catch controls and technical measures to be effective [6].

Technical measures put restrictions to the size and sex of fished species, caught or landed, the gears used, and the times when, or areas where, fishing is allowed. Size limitation would be most effective if individuals below the limit could be returned to the sea alive. Gear restrictions, such as mesh size in traps and nets, control the minimum size of the caught species. Sex restrictions limit the catch of mature egg-bearing females. Empirical evidence suggests that this may be effective, even though the race for fish is not reduced. Time and area closures can be used to protect different species at various life phases. Time closures can protect annual stocks, but also lead to reduced prices as there will be a lot of fish at the market in the beginning of the season [6]. Area closures may stimulate effort redistribution and increase harvesting costs without reaching the goal of reducing fishing mortality. Thus, time and area restrictions are most effective when used together with other measures mentioned in the previous sections [6].

The Norwegian regulations are a result of the quota negotiations with other countries, recommendations from the Regulatory Council and the Directorate of the Fisheries, input from organizations, and political instructions. The quota allocation and the implementation of the fishing are settled through annual regulation instructions [32]. The “trawl ladder” is an important means for allocating cod resources between the coastal and ocean going-fleet, determining a fixed proportion depending on the size of the TAC [33]. There are also annual instructions regarding vessel quotas (VQ), accrual of the fisheries, bycatch and so on, besides the permanent instructions about, for example, gear types and mesh width [32].

3.1.4 The Norwegian fishing fleet

The number of fishing vessels has decreased since the 1960's [4]. In 2005 there were 7 727 registered fishing vessels, of which 1 678 were whole year operated [21]. The Norwegian fishing fleet is among the world's most modern and efficient. The fleet consists of small one-man vessels with hand-line gear to modern factory trawlers producing frozen fillets on board. The variations in technological adaptations have formed a coastal fleet characterized by highly seasonal inshore fishing, to a deep-sea fleet operating year-round in the North Atlantic [4]. The external factors that influence the Norwegian fleet structure are political objectives, the re-

source situation, the management system, subsidies, the receiving and marketing system, the industry structure, and the technology development [4, 34].

The first fishing methods, some 85 000 years ago, consisted of spears, arrows or stones to impale or stun fish, or traps for collecting fish. The development of fishing techniques has followed the evolution of other technical innovations. The advent of steam power, and later diesel engines, made it possible to travel greater distances in shorter time. Woven materials permitted the use of finer and stronger lines for setting, for example, hooks. When steam power was introduced, vessels were able to tow large fishing gears at relatively high speed over long distances, independently of the direction or speed of the wind [6].

In the 1820's, ice was introduced to prolong freshness, but it was not until the 1920's that freezing became common. At the same time the invention of the engine-powered mechanical hauling devices, and 10 years later; the development of the low- pressure hydraulic system, was an important breakthrough in fishery technology. The fishers got fingertip control of fishing and gear-handling operations [6].

Important inventions as a result of World War II were the acoustic equipment for detection of submarines which led to development of efficient devices for fish finding, for example the echo sounder and sonar. Another invention was the radio navigation systems such as Decca, Loran, and the recent satellite navigation systems. The radar also gave the fishers increased safety at sea. The development of synthetic materials for ship building and net-making enabled enormous mid-water trawls and vast purse seines with huge catching capacity. Large size nets could be handled as a result of the development of the hydraulic power block. The factory ships; large diesel-powered vessels combining the use of high-tech fish finding and navigation equipments with huge nets made from synthetic fibers, the use of filleting machinery and rapid freezing technology, have been (over-) exploiting the oceans now for decades [35]. Modern freezer and cooling technology ensures that catches arrive to the market at the highest possible prices [6].

Fishing methods may be divided into two categories; active or passive. Active fishing gears are propelled or towed in the pursuit of the target species, while passive gears are characterized by the fact that the species have to move into or towards the gear [6, 23]:

- Passive fishing gears: Fish line, nets, fish trap, and fish pot
- Active fishing gears: Purse seine and trawl

The most important gears in Norway are trawl, purse seine, fish line and nets [23]. More information about fishing gears can be found in [6, 23, 36].

3.1.5 Overcapacity

Overcapacity is a major problem in the world's fisheries [4, 8, 37–39]. Fundamental drivers to overcapacity are open access, resource rent, technological development, and subsidies for investments and operation. Overcapacity reduces the

possibility for achieving sustainable fisheries management, because overcapacity threatens the fish stocks, the profitability, the employment, and the settlements along the coast. In quota regulated fisheries, such as in Norway, overcapacity causes reduced profitability, and strong incentives for illegal fishing. Reduced profitability means that the fleet is more exposed to variations in quota sizes, and the risk of illegal fishing causes large and expensive control needs [4].

Fisheries technology is connected to a vessel's catch capacity. Investments in the fishing fleet do not necessarily lead to increased production. When the level of maximum sustainable yield is achieved, it is nature itself that decides the abundance of fish, not the amount of investments. Catch effectiveness may be improved, resulting in fewer employees, more comfortable working conditions and higher fish quality. However, improved effectiveness and overcapacity also lead to overexploitation of the fish stocks and conflicts between vessel groups, regions and countries [20].

In Norway, the vessels are getting broader compared to length and there is an increase in tonnage as a result of higher complexity, better performance, higher capacity of main engine and more power of auxiliary machinery, such as deck equipment, thrust of main engine, in addition to thermal capacity for operation of cold storage rooms and processing capacity. This development has led to an increased operating efficiency; and increased costs [7].

Capacity in the fisheries is a concept with different interpretations, as one of the most important premises for fishing; the fish stock, fluctuates, besides usually being free of charge to the fishers [4]. Fishing technologists often refer to capacity in terms of the technological and practical capability for a vessel to achieve a certain level of activity. Capacity for fisheries scientists is often related to fishing effort, and that of fishing mortality. Fishing mortality is the proportion of the fish stock killed through fishing. Effort is also an ambiguous concept, as it may describe all inputs employed in the harvesting process [40].

In general, it not possible to measure all inputs. Thus, indicators are used, e. g., total days fished, or kilometers of nets used. The measure of effort may be related to fishing mortality. If total fishing mortality exceeds the desired target level, the fishing mortality rate is too high due to fishers having produced too much fishing effort. The desired target level may be a biological reference point relating to, e. g., maximum sustainable yield. If fisheries management regulations can ensure that effort levels do not exceed target fishing mortality rates, then capacity is often not considered an issue even though the fleet size may be larger than required [40].

Fisheries managers often link capacity more directly to the number of vessels operating in the fishery, especially when the use of input controls, such as fleet size and effort levels, are the main means of control. Capacity may be expressed in measures such as gross tonnage or in terms of total effort, e.g., standard fishing days. If there are no restrictions on effort, these measures may indicate that too many fishing vessels may produce too high a catch. Then overcapacity may be considered to exist if the fleet is larger than desired. Thus, a link is somewhat established between existing and target levels of effort and fleet size [40].

Fisheries managers may also be concerned with vessel utilization. Underutilized capacity is vessels fishing less than what would be their expected “normal” number of operating days, and thus catching less fish than their potential. Catch or effort restrictions may often cause such a situation. As management may tend to think of capacity in terms of inputs, economists tend to consider capacity as some level of potential output that could be produced if the vessel was operating at maximum profits. The economic definition of full utilization considers that additional revenue must at least equal or exceed the additional cost of catching more fish. Thus, full utilization in an economic perspective may be less than what is technically possible for the vessel [40].

Economic perspectives on capacity changes in the fishing fleet may not give much information about a vessel's actual catch capacity and the capacity utilization, and require a lot of economic information available. A crew on board a fishing vessel may still gain a high income even when the vessel suffers from economic problems, because they share the total income from the fishery. Therefore, a vessel may achieve a profit without a maximal utilization of the catch capacity. In addition, a vessel's economic result is related to important external conditions, such as the resource allocation between certain gear and vessel groups, market prices at a given point in time etc. Thus, changes in these factors may have a large impact on the vessels' overall operating profits [7].

Capacity measured solely in terms of economic terms, is very different from the social scientific approach. In a social scientific perspective, the household unit and the local society are included in the equation. The fisher adjusts fishing to sustain a reasonable economic outcome to the household. An example of this is the Lofoten cod fishery, where coastal vessels fish for the cod with conventional gear that have been adapted to the cod's migration pattern during 3 to 4 winter months. Failure to utilize the operation equipment outside the Lofoten fishery is not regarded as unprofitable overcapacity in a social scientific perspective, but as a natural adjustment to the cod's migration pattern [7]. According to Johnsen [41], discussing capacity from the perspective of a social scientist, fisheries policy and management fail to see capture capacity as an effect of network relations, instead of a product of the individual actions of rational economic actors. Thus, the capacity will continue to increase. His recommendation is to acknowledge the relational effect.

Even though there are differences, the concepts may be considered to be complementary. Catch effort and fleet size are correlated, although the utilization of the vessels may affect these. FAO [39] defines fishing capacity as “the amount of fish over a period of time (year, season) that can be produced by a fishing vessel or fleet if fully utilized, for a given resource condition”. Capacity utilization is “the ratio of actual output (catch landings) to some measure of potential output (capacity output) for a given fleet and biomass level”.

Overcapacity may therefore be defined as “a situation with capacity output greater than target output”. On the other hand, overcapitalization refers to a situation where actual capital stock is greater than the optimum capital stock required to produce the fish. Although Norwegian authorities have introduced several re-

restrictions, such as TAC, IQs, licenses, and other regulatory measures, the problems connected to overcapacity persist [4, 7].

The different perspectives on capacity appear when considering fisheries management responses to the problems of excess capacity. If the vessels fished for fewer days, the level of effort would decrease. For the fisheries scientist, the problem of overcapacity would disappear. Still, the problem would remain for the fisheries manager, where as it would be worsened for the economist, because the reduced utilization would result in lower levels of profitability. Another option could be to reduce the number of vessels in the fishery. Then the effort level would also be reduced, the remaining vessels would be allowed to operate more effectively, making the scientists, managers, and economists happy [40].

According to Standal [7], a better way to analyze the actual capacity development in a longer time perspective is to establish technical parameters, such as length/breadth ratio, gross tonnage weight (GTW) etc., that determine a vessel's overall capacity. The catch capacity of fishing vessels refers to the sum of a number of technical parameters, as fishing vessels are complex structures. Thus, an important premise for a technological perspective on the capacity development for the different gear and vessel groups, is the development of a measure which includes the technical parameters of vessels in the total equation. In this way, it is possible to describe the capacity development independently of external conditions that impact the economy of the fishing fleet.

Overcapacity is recognized as the most important reason for overexploitation of the fish resources. Even though the fisheries management in many countries aim at controlling and reducing the fishing effort, the catch segment is characterized by overcapitalization and overcapacity. Overcapacity is not a new phenomenon, and was described as early as 100 years ago. However, the problem was first taken seriously by authorities and organizations in the 1990's. Sometimes overcapacity is described differently in a short term and a long term perspective. In a short term perspective, there is overcapacity if the fleet has too high capacity compared to the current catch level. In a long term perspective, overcapacity is when a fully utilized fishing fleet has too high capacity to keep the stock at MSY. In Norway structural efforts have been implemented to reduce the catch capacity. However, since most fisheries experience stock fluctuations and seasonal variations, there will exist a gap between available catch capacity and available resources once in a while. Increased emphasis put on the quality of the fish may also cause more investments as improved quality requires more time and space on board the vessel. In the Norwegian fishing fleet, there seems to be overcapacity among the large trawlers and the shrimp trawlers. Regarding the coastal fleet, it is more difficult to draw any conclusions, however, estimations of the technical capacity show a strong increase in recent years [4].

3.1.6 Sustainable fisheries

Sustainable use of renewable resources is a widely accepted goal [42], and it is the main objective of the Norwegian fisheries management [43]. Operationaliz-

ing the concept of sustainable fisheries means to relate the concept to a specific political, cultural, and resource situation [20]. Different perspectives on sustainability appear when the stakeholders to the fisheries and their needs are analyzed [44], and the conflicting views cause difficulties in achieving sustainable use of resources [42].

The global situation today is characterized by reduction and almost collapse of many fish stocks. The reason is hardly lack of regulation. The fisheries in Norway and in the western world are managed by effort regulations and catch control. There are several reasons for failure of the management systems [45]:

- Wrong scientific recommendations for TAC
- International negotiations pushing the quotas above the recommended scientific level
- High by-catches
- Cheat
- Pollution and climate changes

Sustainable development consists of social, ecological, and economic dimensions. Some authors also add institutional sustainability to this list [24, 46]. Institutional sustainability is described by Charles [24] "...as the sets of management rules by which the fishery is governed, and the organizations that implement those rules...". This dimension is considered to be outside the scope of this thesis, even though the dimensions of sustainability are interlinked.

The ecological dimension involves exploitation of the fisheries with a long-term perspective in mind, which means that future generations also must be able to fulfill their needs for fish (Fig 3.4). The precautionary principle, nature's carrying capacity, and maximum sustainable yield (MSY) are concepts related to the environmental dimension [47]. The precautionary principle is a disputed issue, but Principle 15 of the Rio Declaration of the UN Conference on Environment and Development in 1992 [48] states that "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

According to FAO Code of Conduct for Responsible Fisheries, Article 6.5 [27], the "States and subregional and regional fisheries management organizations should apply a precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment, taking account of the best scientific evidence available. The absence of adequate scientific information should not be used as a reason for postponing or failing to take measures to conserve target species, associated or dependent species and non-target species and their environment". Key concepts have been the burden of proof (i. e., the responsibility for providing relevant evidence) and the standard of proof (i.e., the criteria to be used to judge that evidence) [49].



Fig. 3.4. Barbecuing seafood. Permission by the Norwegian Seafood Export Council. Photographer: Arild Juul.

An analogy to the application of the precautionary principle may be drawn to the differing standards of proof used in civil and criminal law. Variations in the burden of proof on whether to carry out an action or not, may involve an analysis of the costs, benefits, risks, and consequences of the action [24, 50]. The precautionary principle is incorporated into the management of the Norwegian fish resources, as a precautionary approach, which means that the degree of uncertainty in a stock assessment should determine the extent of exploitation [51].

Fishing contributes to human welfare by fulfilling needs for employment and income, cultural needs and recreation [46]. These aspects are captured in the social dimension of sustainability, which also includes human rights, moral and justice [52]. The fisheries policies should be based on democratic principles, such as stakeholder inclusion and distribution of power [20]. Safety is another important aspect of the social dimension of sustainability, because accidents cause grief, stress and loss of social security. Statistics of the fisheries show that the profession is one of the most dangerous. The high accident risk affects new recruitment, as young people may have other expectations and demands than the old fishers. The high accident rate is also an economic problem; skilled employees disappear, and insurance costs are high [53].

The economic dimension of sustainable fisheries is related to maintenance of human-made capital. This may involve the controversial concept of sustainable growth. Damage caused by the catching process and the handling of the fish on-board the vessels, influences the quality of the fish meat. Such damage may reduce the price paid for the fish and cause income loss [54].

Thus, a sustainable Norwegian fishery should be exercised without causing unwanted changes to nature's biological and economic productivity, the biological diversity or ecosystem structure from one generation to another. It should be exercised without a disproportionate consumption of non-renewable resources, and without challenging nature's carrying capacity. The authorities and the scientific community should base their recommendations and decisions on the precautionary principle. The fisheries should be exercised and managed so that social structures, knowledge and traditions are secured, and stakeholders are heard [20]. The fisheries should also be profitable, a safe workplace, and be an attractive way of making a living.

3.2 Objectives

The main objective of this thesis has been to develop a framework that integrates a technological perspective into fisheries management in order to define, evaluate, and improve sustainability in the Norwegian fishing fleet.

More specific objectives were:

1. To discuss and clarify the main concepts; sustainability, sustainable fishing fleet, and overcapacity.
2. To identify technological, ecological, social, and economic factors that influence sustainability in the fishing fleet.

3. To define and discuss indicators and acceptance criteria that can be used to measure and monitor sustainability in the fishing fleet.
4. To analyze and compare sustainability between a Norwegian fishing fleet and another production system, for example the cod-fishing fleet and cod-farming.

3.3 Delimitations

The thesis work has been limited to the Norwegian fisheries in Norwegian territorial waters.

There are several attributes that may be used to describe sustainability in the fisheries, depending on how the system boundaries are defined. Since the main problems addressed in this thesis are sustainability and overcapacity, the system boundaries are limited to the fishing fleet, shown in Figure 3.5. This means that the marine ecosystem in where the fishing vessels are interacting, is outside the thesis' boundaries.

The fishing fleet has a reciprocal dependency relationship to the fisheries industry, and the other parts of the value chain. Changes that affect the capacity of the fishing fleet will affect the rest of the value chain. However, the thesis work is limited to issues regarding the fishing fleet.

Institutional sustainability is not evaluated in the thesis, because the fisheries institutions, such as the authorities and organizations, are considered as external conditions to the fishing fleet, even though they are recognized as stakeholders.

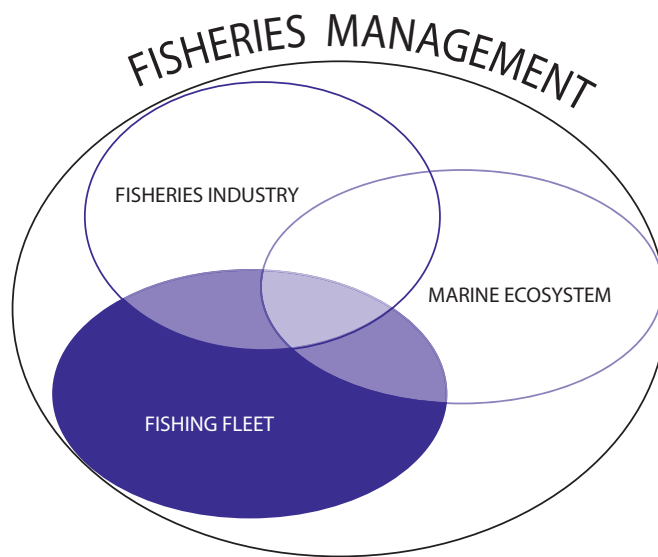


Fig. 3.5. The system boundaries for the thesis. The shaded areas indicate that the fishing fleet as a system interacts with other systems, such as the fishery industry and the marine ecosystem.

Research approach

Sustainability cannot be investigated within the limits of a single scientific discipline, because it involves several disciplines, such as ecology, economy, engineering, law, physics, politics, and sociology. This multi-disciplinarity introduces cross-disciplinary communication problems that cause conceptual difficulties and unclear measures of sustainability [55]. Any attempt to analyze aspects of sustainability in the fisheries requires a broad systems perspective. Fisheries are complex structures, and by using a systems perspective it is easier to look at “the big picture” to achieve a better understanding of the properties [24]. System analyses are carried out to assess different alternative approaches that may be suitable to meet an identified need [56].

4.1 System science theories

System thinking has emerged after World War II as a response to fundamental problems of science. These problems are related to complexity in general, to the extension of science to cover social phenomena, and to the application of scientific methodology in real-world situations (management science). The ability to cope with complexity is connected to reductionism as the aim for scientific explanation. Complexity of the real world is reduced into experiments whose results are validated by their repeatability, and knowledge is gained by the refutation of hypothesis. Descartes rule of dividing the problems being examined into separate parts assumes that the components of the whole are the same when examined singly as when they are part in the whole, and that assembling the components into the whole is straightforward [57]. System thinking is an attempt to handle the problem of complexity by focusing more on the wholes and their properties which complements scientific reductionism. Thus, the top-down approach is important, which means to view the system as a whole, break the system into components, study them, and put the system back together, as it is impossible to study the components separately. For example, our knowledge is divided into different

disciplines, such as physics, biology, sociology. This division is human made, and it is hard to see the unity which underlies this division [57].

System science or system theory is applicable in a wide variety of areas, and argues that the world, even though complex or diverse, can be described by concepts and principles which are independent from the specific subject area. By uncovering those general laws, it is possible to analyze and solve problems in any domain and to any type of system [58]. The word system comes originally from Greek; *systema*, which means an “organized whole” [59]. There are many definitions of systems, and the International Council on Systems Engineering (INCOSE) gives the following one: “A system is a combination of interacting elements organized to achieve one or more stated purposes” [60]. A system is contained within some kind of hierarchy, for example: A fishing vessel is part of a fishing fleet which is operated in specific geographical environments, which are parts of the world.

Social sciences may face more vague and complex problems than that of natural sciences, and social institutions are not available to experimentation. There are many ways to interpret social phenomena, for example, there is a problem related to predicting social happenings, because prediction may influence the outcome of a social system. Knowledge gained from experiments should be repeatable and independent of opinion, speculation and preferences. However, also scientists are human beings, which means that they do not behave completely rationally [57].

Problems of management are related to taking decisions in a social system, for example, regarding “how should schools be designed?”, and “what type of fighter plane should the government choose?”. These are real-world problems facing a decision in contrast to scientist problems in a laboratory, which are possible to define and limit. Operational research (OR) evolved as a response to the scientific failure of making progress in application of management issues. Operational research works with applying methods of science to parts of the real world. A definition of OR is [57]:

“Operational Research is the application of the methods of science to complex problems arising in the direction and management of large systems of men, machines, materials and money in industry, business, government, and defense. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies, or controls. The purpose is to help management determine its policy and actions scientifically”.

OR came to be applied outside the military forces after World War II, to problems where the decision-maker had a clear objective in mind. System analysis began to be applied to aspects that OR had considered as “given”, and accepted models that some people did not find scientific. Thus, it has been suggested that OR should be confined to efficiency problems and system analysis to problems dealing with the “optimal choice” [61]. Even though OR may give valuable contributions to, for example, well-defined production processes, OR still faces severe problems when methods of science are transferred to very complex areas [57].

It was biologists who were the early system thinkers. Microscopic examinations of organisms led to the view that in living things there exists a hierarchy of

structures; molecules, organelles, cells, and so on. In the 1940's, Ludwig von Bertalanffy generalized "the system theory of the organism" into thinking concerning systems in general, and in 1954 he helped to found the Society for General Systems Research [57]. Bertalanffy and companions claimed that there were some general ideas applicable across several different scientific disciplines; for example, atoms, cells, organs, groups, organizations, societies, and solar systems all belong to the concept "systems" [62].

System thinking is founded upon two pairs of ideas- emergence and hierarchy, and communication and control. The concept of organized complexity became the subject matter of the concept of the new discipline "systems"; there exists a hierarchy of levels of organizations, each level more complex than the one below. A level is being characterized by emergent properties, properties which do not exist at the lower level, such as the shape of an apple: The shape results from a process occurring at a lower level of cells and organic molecules which comprise apple trees, however, the shape has no meaning at that level. The result of this process (the apple itself) gives a new level of complexity with emergent properties [57].

Bertalanffy divided systems into open and closed systems [63]. Open systems interact with its environment, and there may be an exchange of materials, energy, and information [64,65]. In any hierarchy of open systems, maintenance of the hierarchy will necessitate communication of information for purposes of regulation or control. So the ideas from control theory and from information and communication engineering (cybernetics), have made contributions to systems thinking as well as those from biology. All living systems, such as the marine eco-system, are open systems.

There is a fundamental difference between natural systems and man-made systems. This difference is found in the possibility to design the functions of a man-made system, contrary to naturally developing functions in natural systems. Man-made systems give the advantage of controlling the cause and effect relationship [64]. Systems can also be static or dynamic, physical or conceptual. Physical systems are made up of physical components, whereas conceptual systems are some kind of an organization of ideas or a set of specifications and plans. Dynamic systems combine its elements with activity, whereas static systems do not. A system may be a combination of some of the following disciplines or all of them [66]: Technology (hardware, that means all physical equipment), information science (software, that means all conceptual parts, such as programs, instructions, descriptions, orders etc.), economics (finances, that means everything that has to do with costs, revenue, money), and social science (personnel, that means human factors, also called "bioware").

There are very many different systems, such as transportation systems, communication systems, manufacturing systems etc. Boulding [67] identified nine system types by their level of complexity. Levels 1 to 3 encompass the physical systems, levels 4 to 6 the biological systems, and levels 7 and 8 are the human and social system. A level incorporates those levels below it:

1. Level of frameworks, for example atoms of a crystal.
2. Level of clockworks, for example the solar system.
3. Cybernetic systems, which are systems capable of self regulation, such as a thermostat.
4. Open systems, which are systems with a self-maintaining structure, for example a living cell.
5. Genetic-societal level, for example the plant.
6. The “animal” level, characterized by increased mobility, and self awareness.
7. The “human” level, which is the human being considered as a system. This level is characterized by use of language and self-consciousness.
8. Social systems, actors from level 7 who share a common social structure.
9. Transcendental systems, constituted by the “absolute and inescapable unknowables”.

A system must have a purpose, and be able to respond to some identified need. In every case, there are inputs (customer needs), outputs (a system that fulfills the customer needs), external constraints (technology, economic, social, political, environmental), and resource requirements (people, equipment, facilities, materials etc.). There are wanted and unwanted inputs and outputs. Wanted inputs are those materials and the energy the system is using to perform its required functions, for example fish meal used to feed salmon in a net cage. The unwanted inputs are, for example, pollution in the fish feed. Wanted output is grown salmon of high quality, unwanted output may be pollution from the net cage to the surrounding marine ecosystem. Every system has boundaries and boundary conditions. The system boundary determines which elements that are considered as part of the system and which elements that are outside, and the conditions may be risk acceptance and environmental criteria enforced by, for example, the authorities [68].

A systems approach to the fisheries, in a technological perspective, involves connecting and describing objects and events. The Norwegian fishing fleet is a large and complex system to analyze. According to Morgan and Henrion [69] large models require large amounts of human, computational, or other kinds of resources in their construction or operation, however: “If they are organized in such a way that their structure and outputs are easily understood, large models may not be complex”. The size and complexity of such a system, indicates that there may be a large number of possible system developments and outcomes, of which a smaller number of subsets could be sustainable for human beings. In order to overcome the problem of complexity, decomposition of the system is necessary. This means that the total system is decomposed into several subsystems, each again decomposed into lower level subsystems, and at last into the system elements [64]. An example is found in Figure 4.1.

The interaction or interdependence between system components vary with different kinds of systems. The structure of physical systems are highly constrained, compared to social systems, such as organizations, which are loosely coupled [62]. In organization theory, system analysis is found within the open systems perspec-

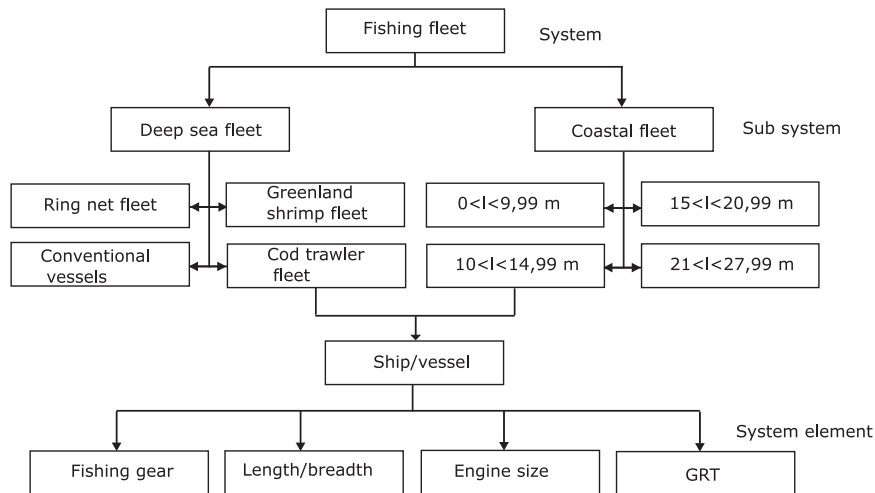


Fig. 4.1. Decomposition of the Norwegian fishing fleet.

tive. Organizations viewed as open systems are defined as “congeries of interdependent flows and activities linking shifting coalitions of participants embedded in wider material-resource and institutional environments” [62]. Other perspectives on organizations are the rational and natural perspectives. A rational system perspective defines an organization as “a collectivity oriented to the pursuit of relatively specific goals and exhibiting a relatively highly formalized social structure”. A definition viewing organizations as natural systems, says that “organizations are collectivities whose participants are pursuing multiple interests, both disparate and common, but who recognize the value of perpetuating the organization as an important resource. The informal structure of relations that develops among participants is more influential in guiding the behavior of participants than is formal structure” [62]. Fisheries management may be viewed as an open system organization, where as the fishing fleet, which is the main system studied in this thesis, is considered as a physical system.

Policy analysis seeks to improve the decision-making in a specific situation. According to Quade [61], system analysis may be helpful in almost any type of public policy-making. Even though critics have claimed that operational research, system analysis, cost-benefit, and cost-effectiveness analysis have not been a success, Quade argues that the problems occurring are often due to applying the wrong type of analysis, or expecting too much from the results.

Nevertheless, public policy problems tend to be far more messy and ill-defined than military and industrial problems; the precursors of policy analysis. In engineering and technology issues, the problems are usually easier to specify than in social problems, and quantitative methods can be of more help to find a solution [61]. This is the starting point for the development of soft systems thinking.

The next sections give a brief introduction to system dynamics and soft system methodologies (SSM), methods belonging to system science theory.

4.1.1 System dynamics

System dynamics is a methodology for studying and managing complex feedback systems, for example in business and other social systems. System dynamics is a method for modeling and simulating the behavior of processes over time as inputs and other variables change [70]. It is a profession that begins with important problems, then comes to understand the causes and structures for the problems, and then finds changes in structure and policy that improves the system behavior [71]. Jay Forrester is the recognized thought-leader, and his earliest application of these techniques was an examination of industrial dynamics [70]. There are four foundations that make industrial dynamics possible:

- Information-Feedback Control Theory which is about the interaction between system components. It improves the understanding of how the amount of corrective action and the time delays in interconnected components can lead to unstable fluctuation
- Decision-making processes, aiming at determining the basis for decisions
- Experimental approach to system analysis. Mathematical analysis is not sufficient to yield general answers. A mathematical model of the system is constructed, the behavior of the model is observed, and experiments are conducted to answer specific questions about the system which is represented by the model
- Digital computers, which facilitate computation and simulation

System dynamics developed from Forrester's book on industrial dynamics [70]. There are several examples of the application of systems dynamics; in public management and policy, corporate planning, biological and medical modeling, the environment theory development in the natural and social sciences, energy systems, and complex nonlinear dynamic decision-making [58, 72]. A simple example of a system dynamics model related to fisheries is [73]:

$$\text{Population next year} = \text{Population this year} + \text{Net production} - \text{Catch this year} \quad (4.1)$$

Net production is estimated by a functional relationship to populations this year, and catch is established outside the model as a driving variable. One problem with this model is that it only makes short predictions. It would be difficult to predict the population 10 years into the future by use of a single equation, as the model can not capture feedback between the population changes and the following production. The solution to this is to view the short term equations as rules, which are calculated repeatedly, by computer simulations [73].

System dynamics has been criticized, for example of including too little, too many, or the wrong factors in the models, and about the selection of a time hori-

zon [74]. However, Haskins [58] claims that system dynamics may be useful when applied in a systems engineering context.

4.1.2 Soft system methodologies

“Hard” system thinking, such as system dynamics, assume that any problem can be formulated as a problem to be solved. In social systems, goals are often vague, and thus soft systems methodologies (SSM) was developed. SSM focus on the definition of the problem in a relevant social context, and may be useful when applied to messy, constantly changing, ill-defined problem situations. The main difference between “hard” and “soft” thinking is that the former starts by asking “what system will meet this need?”, whereas the SSM allows completely unexpected answers at later stages. The “soft” methodology includes a comparison stage where the conceptual models are compared with the real world situation and used to define desirable changes in the real world. The methodology can be seen as a general problem-solving approach to human activity systems.

The sequence of soft systems methodologies comprises four basic mental acts: Perceiving - predicating - comparing - deciding. More specifically, perceiving is about determining the problem situation, predicating is about finding the “root definitions”, which means exploring relevant systems and making conceptual models of them, comparing is about “bringing” the models into the real world and compare possible changes, and deciding is about taking action to improve the problem situation [57].

The outcome of studies concerning human activity systems, with many relevant and often conflicting values, is never an optimal solution to a problem, but a learning which leads to a decision to take certain actions. In general, this will not lead to the problem at hand being solved now, but to a new situation in which the whole process can begin again. Thus, “soft” systems studies leads to a learning system which decides what action to take, action which may or may not be “efficient” with respect to various criteria, whereas the outcome of “hard” systems projects would be expected to contribute to “the science of efficient action” [57].

4.2 Research method

Systems engineering (SE) belongs to system science theory, and SE constitutes the overall framework for the thesis work. The reason for choosing SE, and not systems dynamics or SSM, is based on the thesis’ objectives of “integrating” a technological approach into fisheries management, and of contributing to increased sustainability in the fishing fleet. SE has a broader perspective than system dynamics, and SSM is found too vague and “non-technical” for relevant use. Systems engineering is often related to human-made systems that are physical, dynamic, and open-looped, which the fishing fleet may be an example of.

4.2.1 Systems engineering

In SE, all stakeholders and the whole life cycle of the system are taken into consideration. Traditional engineering methods use a bottom-up approach, whereas SE mainly uses the top-down approach, based on the point of view that the whole is more than just the sum of its parts. One of the most important attributes of the SE implementation is the iterative evaluation process. As the system(s) is analyzed it is also evaluated at the different life cycle stages in order to improve the system through the whole process [66, 75, 76]. Therefore, SE is a suitable process for handling sustainability issues [77].

There are several definitions of SE, but one of them defines systems engineering as the “organized process of defining, designing, verifying, operating, maintaining, and disposing of systems in line with the needs identified by stakeholders and the expectations of the customers”. SE is a method to be used to solve problems that incorporates contributions from many disciplines, by emphasizing the interaction of each part and the “whole” of the system with the environment within which it will be developed, operated, and retired [58].

The SE process is iterative, and can be described simplified into six steps [66, 75, 76]:

1. Identification of system stakeholders and needs;
2. Definition of performance requirements;
3. Specification of system performances;
4. Analysis and optimization of the system (alternatives);
5. Designing and solving;
6. Verification and testing of the system.

The first step is to identify the needs the system has to fulfill. SE belongs to “hard” system thinking, where it is insisted that in the start of a system’s study, it is necessary to define a need. “Problem-solving”, according to this view, means selecting the best way ($S_1 - S_2$), to reduce the difference between the desired state, S_1 , and the present state, S_2 [57].

The answer to the questions “What is needed and why?” results in a list of needs. Functional analysis is the process of translating the system requirements into design criteria. The analysis starts by identifying the functions that the system has to accomplish, based on the needs. Functional, operational, and physical performance requirements to each system element are defined. Translating the “whats” from the functional analysis into “hows” is done by evaluating each functional block with inputs and outputs, external constraints, and then determining the mechanisms by which the function could be accomplished. This leads to the identification of hardware, software, people, facilities etc, through the system life cycle. The functional analysis is the initial description of the system, and serves as a baseline for definition of all requirements. Through the results from the functional analysis, procurement of system components can begin, components are combined into a physical model of the system, for test and evaluation. The top-down perspective is facilitated through the functional analysis, breaking the functions of the system into requirements for each level in the hierarchical structure,

the integration, test, and evaluation steps constitute the bottom-up activity, and should result in a system configuration that fulfills the stakeholders' requirements to the system [75]. For more information about SE, see, for example, [59, 60, 75].

4.2.2 Systems engineering-state of the art

The origins of SE and its first practitioners cannot be precisely established [78], but SE was formed out of the military and space programs that followed World War II, to find ways to handle new technological complexity [79]. The term "systems engineering" was first used by Bell Laboratories in the 1940s, and the first attempt to teach SE was probably made in 1950 at the Massachusetts Institute of Technology [78].

In 1957, Goode and Machol published "System Engineering" [80], in which they describe that in the past 10 years there had been a broadening approach to the problem of designing equipment; called systems design, systems analysis, and often the systems approach. In their book, they try to unify these concepts. During the next forty years, SE continued to evolve to include its definition, description, tools, processes, requirements, implementation, and management [78].

In 1973, Miles [81] describes the systems approach in six steps:

- Goal definition or problem statement
- Objectives and criteria development
- Systems synthesis
- Systems analysis
- Systems selection
- Systems implementation

In the same book, Mueller [82] uses the Apollo project in the 1960s as an successful example of the systems approach: ".In spite of the massive scale of the Apollo program, in terms of both the resources applied and the technologies used, the major issues were ultimately resolved by a small number of people making difficult decisions in the presence of great uncertainties and unprecedented technical complexity". The project organized 200 000 people, hundreds of universities, and 20 000 separate industrial companies to achieve a common goal [78].

Wymore [83] focuses on the interdisciplinary team using a standard SE methodology to approach the problem of the design and analysis of large-scale, complex man/machine systems. The systems engineering methodology described by Wymore is based on a mathematical theory of system design. In 1981, "system-life-cycle-engineering" was introduced as being fundamental to the practice of SE. Blanchard and Fabrycky [84] defined the life cycle of a system or product as starting with the need identification and then carrying out: planning; research; design; production or construction; evaluation; consumer use; field support; and ultimate product phaseout. Blanchard and Fabrycky emphasize that systems engineers must think in terms of the system-life-cycle to ensure that all aspects of the system are considered [78].

Gradually, the perspective of SE as a management technology occurs [78]. Sage [85] is the first to introduce SE as “the management technology that controls a total life-cycle process, which involves and results in the definition, development, and deployment of a system of high quality, is trustworthy, and being cost effective in meeting user needs.”

Several organizations have been engaged in publishing handbooks, standards, and guides about systems engineering. In 1966, The United States Air Force (USAF) was the first organization to publish a comprehensive systems engineering document; Handbook 375-5 which describes a systems engineering process. In 1969, MIL-STD-499 replaced this handbook. A revision to 449 was published in 1974 as MIL-STD-499A to provide criteria for evaluating engineering planning and output, a means for establishing an engineering effort and a Systems Engineering Management Plan (SEMP). In 1979, the U.S. Army published Field Manual, 770-78, Systems Engineering, which describes a system engineering process and guidelines for implementing and managing systems engineering [78].

In December 1989 the Electronic Industries Association (EIA) published a SE bulletin recognizing systems engineering as a central process [78]. A group of 30 individuals from government, industry, and academia met August 1990 in Seattle, Washington to discuss forming an organization with a SE focus. The participants formed the National Council on Systems Engineering (NCOSE), renamed to International Council On Systems Engineering (INCOSE) to recognize the increasing overseas membership [79].

A draft of Mil-STD-499B was released by the US Air Force for review May 1992, which described a SE process more comprehensively. US Department of Defence terminated work on 499B in June 1994, but the EIA together with the Aerospace Industries Association (AIA), the National Council on Systems Engineering (NCOSE), and others tailored a draft version of 499B to create and publish an Interim Standard 632. At the same time, the IEEE wrote and published P1220, Trial-Use Standard for Systems Engineering. In 1995 the National Aeronautics and Space Administration published a Systems Engineering Handbook [78]. ISO/IEC 15288:2002 “Systems engineering- system life cycle processes” is a standard that establishes a common framework describing the life cycle of systems, and supporting life cycle processes within a project or organization [86].

Systems engineering has been successful in introducing systematic rationality into decision-making, when the problem is to choose between different alternatives to achieve an efficient result. There have been attempts to apply the “hard” concept of SE in problems “softer” than those of engineering and defense economics [57]. Today SE is used in several industries, such as in the automobile industry, in large data and communications projects, in the oil and gas industry, and in the energy supply industry. In 2006, the Norwegian Center of Expertise (NCE) Systems Engineering Kongsberg was established, in which several companies participate to improve innovation and technology development [87].

There is not much literature on SE related to fisheries, however, two systems engineering projects were carried out in U.S. east coastal fisheries in the 1970's. Hamlin [88] argues that the fishing industry can benefit from use of systems en-

gineering, and that systems engineering can be used at all levels of application, from evaluating a simple change in a fishing procedure to managing and guiding the industry on a global scale.

4.3 Scientific approach

The research carried out in this thesis differs from the classical natural science research. The work has not been experimental, but developmental and exploratory. The purpose of the work has not been to develop new models, but to apply and adapt existing methods and knowledge within new application areas.

The scientific foundation of this thesis is both that of natural sciences and social sciences. The fishing vessels and the fishers are affected by technological development, the abundance of fish, and economic profit. The abundance of fish is dependent on natural variations and environmental disturbances from humans. The human population are dependent on fish for food, and employment is important for settlement and welfare. Fishing is also a recreational activity, and represents a source of income for individuals and the society.

The fisheries is a large and complex system, and thus some limitations have been made (see Sec. 3.3). Within these limits the most relevant “disciplines” of the thesis have been fishing vessel technology and engineering, system analysis, and decision theory.

In social and humanistic sciences it is more common to use qualitative methods than in natural sciences which traditionally emphasize objectivity and quantification. The thesis deals with clarification of relevant concepts and development of a methodological framework by using existing and well-recognized methods. Both qualitative and quantitative methods have been used.

4.4 Scientific evaluation

Scientific quality is not a clear concept. According to the Norwegian Research Council [89], quality is related to three aspects:

- Originality; to what extent the research is novel and has innovative use of theory and methods
- Solidity; to what extent the statements and conclusions in the research are well supported
- Relevance; to what extent the research is linked to professional development or is practical and useful to society

In some cases, these aspects may be contradictory. High solidity due to thoroughness may restrain creativity, and research of little originality still may be very useful to society. In multi-disciplinary research, it is necessary to evaluate the synthesis of the research elements, in addition to the quality of the elements in separate.

An essential part of the quality assurance of the research in this thesis has been carried out by using peer reviews through publication in international journals. Stakeholders in the fisheries have been consulted formally and informally. The author has also attended seminars, workshops, and international conferences to present status of research, to get feedback from peers, and learn about the latest progress in the field of research.

4.5 Scientific approach to uncertainty

Previously, science was understood as achieving ever greater certainty in our knowledge, and control of the natural world. Today the world is facing environmental challenges and threats, such as the greenhouse effect and hazardous wastes, which give rise to different types of problems than those solved by the traditional science. Such problems inherit crucial uncertainties, and quality assurance of scientific research and information provided for decision-making is of utter importance.

The new scientific issues have a global and long term impact, and quantitative data are often inadequate. Science cannot provide well-funded explanations of natural phenomena and theories based on experiments. At best, mathematical models and computer simulation can give some information, which often is untestable. Thus, it is not possible any longer to assume that certainty is guaranteed by mathematics.

Policy-makers want straightforward and certain information as input to their decision-making. However, issues regarding policy-related research involve a high degree of uncertainty, and often social and ethical aspects as well. Simplicity and precision in predictions are not feasible in many cases. Uncertainty is found at all levels in scientific research, and is often in environmental and technological issues referred to as "risk". Risk may refer to some unwanted event, and is usually a function of its likelihood and its harm. Measuring risk is in itself not an exact operation, often risk assessments are based on computer models or expert opinions. Such outputs are related to unreliability. The issue of what risks are and whether they can be measured, remain unresolved. So is the problems of causation; what makes events occur rarely, frequently or never [90].

There are different types of uncertainty:

- Parameter uncertainties, which arise from the quality or appropriateness of the data used as inputs to models.
- Modeling uncertainties, which arise from incomplete understanding of the modeled phenomena, or from numerical approximations that are used in mathematical representations of processes.
- Completeness uncertainties refer to all omissions due to lack of knowledge.

The two first can be reduced by using different techniques, but the last one cannot be reduced. Policy related research often faces contradictions of severe uncertainty, because the political dimension influences the reception of the results, as well as the framing and existence of the research project [90].

Zio and Apostolakis [91] classify uncertainty as epistemic and aleatory. To describe the difference between these uncertainties, they introduce the concept of the model of the world. Many existing physical phenomena cannot be represented by deterministic models of the world, and scientists construct models of the world that incorporate uncertainty in these physical phenomena, for example a Poisson model used to represent the probability of earthquakes over a given time period. Aleatory uncertainty occurs due to “random” or “stochastic” variability of the phenomena contained in the world model formulation, and deals with the randomness or predictability of an event. This means that it cannot be predicted exactly when there will be an earthquake, even if a large quantity of data is taken into consideration.

Every model of the world is conditional on the validity of assumptions and the parameter values. The Poisson model is conditional on the assumption of a constant rate of earthquake occurrence, and the numerical rate of this parameter may also be uncertain. These uncertainties, regarding our knowledge about the numerical values of the parameters and the validity of the model assumptions, can be captured in an epistemic probability model. According to Zio and Apostolakis [91], this means that model and parameter uncertainties are of the epistemic type.

“Decisions under uncertainty should be judged by the quality of the decision-making, not by the quality of the consequences” [92].

Main results

This chapter contains a summary of the main results of the thesis. More specific results and details are presented in the articles in part II. Sect. 5.1 explains the main methodological contribution of the thesis (the framework), and Sect. 5.2, Sect. 5.3, and Sect. 5.4 more specific results based on use of the framework.

5.1 Systems engineering as a methodological framework for improved sustainability

One of the premises for the thesis was to integrate a technological perspective into fisheries management, because sustainability of the fishing vessels and the gear are strongly linked to technological development. The nature of sustainability requires a systems perspective. There are different system analysis methods, but from a technological perspective, dealing with multidisciplinary tasks, systems engineering was selected as the most feasible process (Chap. 4). In the thesis, systems engineering has been applied to develop a framework for fisheries management (and other stakeholders to the fisheries) as means to improve sustainability in the fishing fleet.

The aim of the framework is to improve:

- The understanding of sustainability in the fisheries, with main emphasis on the fishing fleet
- The understanding of need analysis among stakeholders to the fisheries
- The use of performance specifications and regular evaluation of the fishing fleet
- The way to perform trade-offs for prioritizing objectives and balancing various attributes, such as costs, safety, etc.
- The overall presentation and communication of information about the fisheries and the fishing fleet

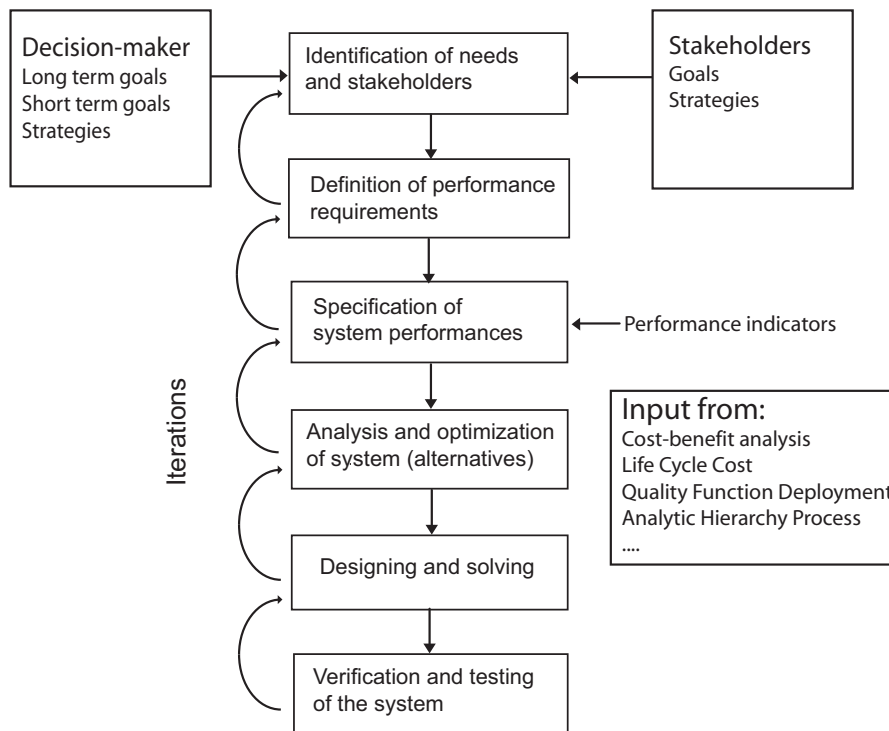


Fig. 5.1. The structure of the framework based on systems engineering.

The framework follows the systems engineering process (Sec. 4.2.1) by emphasizing the definition of the problem, analysis of stakeholders, specification of requirements to sustainability, trade-offs, and the iterative process of evaluation.

The framework is based on the following items:

- When solving a problem, stakeholders' needs have to be analyzed and prioritized, according to their degree of involvement and their relationship to the problem
- The requirements to the solution needed to solve the problem, should be as specific and quantitative as possible
- Several methods, from article 2, 3, 5, 6, and 7 can be used to give input to the decision-making process
- The solution or system alternatives have to be evaluated systematically, for example, by use of indicators, which means that quantitative information has to be available
- Systems engineering focuses on iterative evaluations, which means that the goal achievement should be specified, such as criteria for greenhouse gas emissions (article 6)

In Figure 5.1, the starting point is that a decision-maker faces a problem, such as high energy consumption, implementation of a risk reduction policy, the use of new technology, etc. Problems in the fisheries affect stakeholders, so decisions have to involve stakeholders. Adequate decision alternatives need to be generated and evaluated, and they may have rather large consequences that relate to economic performance, possible accidents leading to loss of lives and/or ecological damage; consequences that may influence the sustainability of the fishing fleet. Systems engineering is considered to give valuable decision support in such situations. The framework is based on the idea that effects on sustainability should be included actively in the decision process, even though the differences in management and decision level will vary, depending on if, for example, the decision-maker is a person or a group of persons in the Directorate of the Fisheries or Ministry of Fisheries and Coastal Affairs.

The overexploitation of fish is the primary driver for the need for sustainable fisheries and a well-functioning management system. Thus, fish may be considered as part of the natural system interacting with the human-made system of the fisheries and fisheries management. Problems regarding sustainability in the fisheries are not only a technology development problem, but also an organizational challenge. However, the focus in this thesis is within the technological perspective, which means that the fishing fleet is the main target for problem solving. Systems engineering is not applied as an attempt to change the structure of fisheries management, but as means of suggesting a decision-making process that improves sustainability in the fishing fleet.

The concept of sustainability is vague, and fisheries management does not have clearly stated definitions of sustainable resource management and a sustainable fishing fleet. There is a lot of information available about the Norwegian fisheries, but this information is fragmented and difficult to use in assessments of sustainability and management evaluations of its goal achievement. Fisheries management has been criticized for its lack of systematic policy evaluations [93], and the main results of this thesis shows that the systems engineering process may be used to facilitate such evaluations.

Article 1 describes use of systems engineering principles in fisheries management. Fisheries management involves decision-making in situations often characterized by high risks and uncertainties, and it may be difficult to predict the outcomes of the decisions. Systems engineering has been introduced as a multi-disciplinary approach to sustainable fisheries management to contribute to increased visibility and reduced risks in the decision-making process. Article 2, 3, 5, 6, and 7 discuss and use a number of tools that are available to support decision-making, such as cost-benefit analysis, risk acceptance criteria, life cycle cost (LCC), the Analytic Hierarchy Process (AHP), and Quality Function Deployment (QFD). Nevertheless, these tools do not provide “correct” answers; they have limitations, they are based on a number of assumptions, and their uses are based on scientific knowledge as well as value judgments involving political, strategic, and ethical issues. This means that these methods leave the decision-makers to

apply decision processes outside the practical applications of the analyses, to which the framework offers guiding principles and structure.

The main outcome of using systems engineering principles in fisheries management, is that the framework offers a broader analytical perspective to fisheries management and sustainability, which acknowledge that sustainability cannot be distinguished from the context. The framework gives a structure for classification of sustainability in the fishing fleet, and a procedure for taking into account concerns that occur when searching for the best decision alternative. The life cycle approach means that decisions regarding sustainability and design of sustainable systems have to have a long-term focus, because sustainability implies considerations of consequences for future generations.

Today, most input to fisheries management come from biology and economy, such as stock assessments and profitability analyses. In systems engineering, information from different scientific disciplines, e.g., biology, social sciences, economy, and technology, are necessary input to the analyses and decision processes, because fisheries management is much more than bio-economics. Application of the systems engineering process in fisheries management and the inclusion of technology introduce new perspectives, new disciplines, and new stakeholders into the decision-making process in the fisheries.

Another important result is the focus on stakeholders and their needs. If fisheries management is to evaluate their own effectiveness in achieving sustainable resource management, it is necessary to know who the stakeholders are and their relationship to the system. Knowledge about the stakeholders is a premise for determining requirements to the system, and the requirements are important if fisheries management is to know what “sustainable fisheries” really is. This is further discussed in article 1.

One of the most important attributes of systems engineering is the continuous evaluation process. As the system is analyzed, it is also evaluated at the different life-cycle stages in order to improve the system through the whole process. Development of attributes and indicators to evaluate the sustainability performance of the fishing fleet, as discussed in article 2, are results from using systems engineering.

Article 8 discusses the relationship between sustainability in the fisheries, risk management, and functional rules. The top-down approach of systems engineering and the need for a “holistic” perspective regarding sustainability, may indicate that functional rules are more feasible for regulating the fishing fleet. Today, the fishing fleet is exposed to length restrictions (detailed rules), however, limitations to energy consume (functional rules) would be a more sufficient way to manage the fishing fleet, in a systems perspective.

5.2 The concepts of sustainable fisheries and overcapacity

Sustainability in the fishing fleet implies a thorough understanding of the concept of sustainability as well as knowledge about the fisheries and the fishing

fleet. There exists no common definition of sustainability and sustainable development, which means that many aspects related to these concepts have to be considered. The concepts have been discussed in article 1 and 2, and further elaborated in Sect. 3.1.1 and Sect. 3.1.6. Sustainable fisheries should fulfill the need for fish for present and future generations.

The fisheries are complex and the Norwegian fishing fleet comprises a wide variety of vessels. Sustainability consists of (at least) a social, ecological and economic dimension. The social dimension is related to the needs of human beings, such as the need for a safe workplace. In the thesis, safety is considered as an important aspect of sustainability, and emphasized in the analyses. The ecological dimension is related to conservation of the marine resources and in the end; the global environment. The economic dimension is related to human needs for profitability. Fisheries management is the human means for achieving sustainability within these dimensions, and use of technology may contribute to fulfilling the human needs within the sustainability dimensions.

The problem of overcapacity is thoroughly discussed in Sect. 3.1.5. In this thesis, the technological approach to sustainability in the fisheries implies a perspective on catch capacity, in accordance to Standal [7]. Thus, the vessels' catch capacity is measured by technical parameters, for example length, breadth, type of fishing gear, and gross tonnage weight. For the ocean-going fleet, the overcapacity can be measured by comparing the actual days at sea to the total number of operating days that could be expected during a year [4].

5.3 Classification of sustainability attributes

To specify the most important characteristics of sustainability in the fishing fleet, attributes were determined. Figure 5.2 shows the connections between threats to sustainability caused by external conditions, the dimensions of sustainability, the attributes of a fishing fleet, and the system alternatives of the Norwegian cod-fishing fleet. The proposed attributes are selected based on a synthesis of reviewed literature, found in article 2.

Figure 5.2 is based on the system boundaries, which focus on the fishing fleet in the operational phase (Sec. 3.3). Improved sustainability in the fishing fleet will improve sustainability in the fisheries, leading to improved sustainable resource management.

The system boundaries determine which attributes are relevant for assessing sustainability in the fishing fleet. Sustainability in other parts of the value chain, for example, in the fisheries industry, may emphasize stable deliveries of fish (supply steadiness). The selection of attributes depends on the system to be evaluated, and there are differences between the attributes used for evaluating sustainability in the fishing fleet (article 2) and those used to assess sustainability of cod-farming vs. cod-fishing (article 4). Thus, there is no true solution to the selection of attributes because the decision-situation determines which attributes to use. The

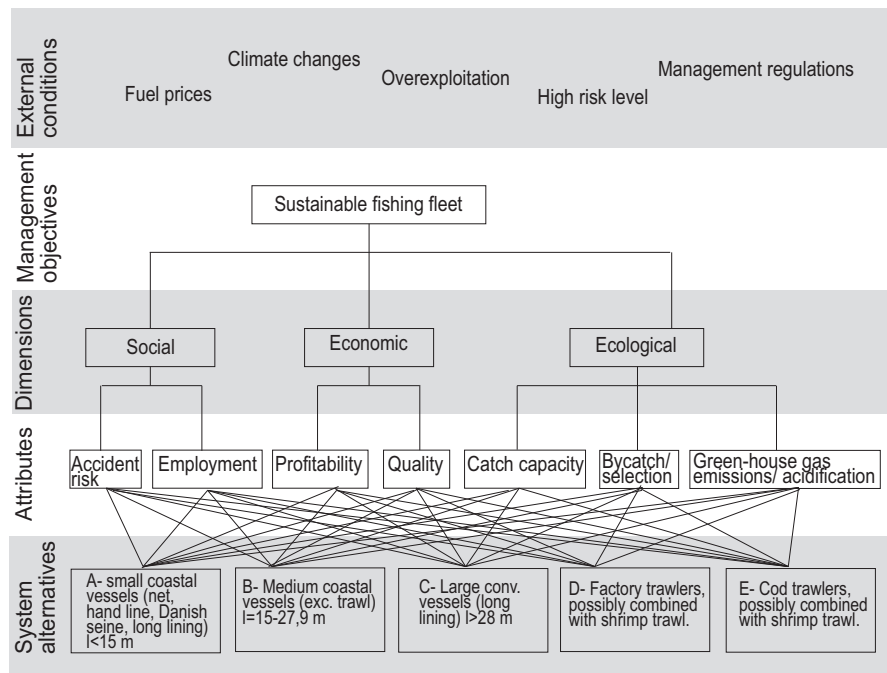


Fig. 5.2. Sustainability attributes of the cod-fishing fleet.

main point is, however, to consider all aspects of the system, that means within the dimensions of sustainability, and not only costs or environmental impact.

The evaluation of the cod-fishing fleet in article 2 shows that there are differences in the performance of the vessel groups. These differences pose a major challenge to fisheries management in their decision-making regarding sustainability in the fleet. The smallest vessels have the lowest fuel consumption (kg fuel/kg fish), but they have a very high accident risk (FAR). The evaluation of cod fishing vs. cod farming in article 4 shows that the potential growth in the cod farming industry may cause changes in the management system of the cod fisheries, such as a possible shift from the IVQ-system of today to an ITQ-system.

5.4 Measuring sustainability

As previously mentioned, the Norwegian fisheries management lacks frequent evaluations of its policies [93]. Article 1, 2, 3 and 6 discuss issues related to the fragmented information that characterize fisheries management, and that sustainability should be evaluated on a regular basis by use of performance indicators and criteria. Sustainability in the fishing fleet may be described and characterized by the attributes, but indicators have to be identified in order to measure the system performance within the attributes.

Article 2 shows that the performance indicators should be measured on a regular basis for fisheries management to determine if sustainability increases or decreases. For simplicity, the indicators could be aggregated into a sustainability index showing the overall system performance. Aggregation implies simplification and weighting of the indicators, which means that such an index should be used with care. Sustainability implies a long-term perspective when taking decisions, and the performance evaluations can give indications of trends, which means that the results can be used to predict consequences in the future, based on the current development.

Article 5 focuses on Life Cycle Costing (LCC) as an important tool in the system design process. The initial costs are just part of the total picture, because the operating costs may be substantially higher during the system life time. Regarding the fishing fleet, the fuel consumption occurs in the operational phase, causing environmental problems as well as impact on profitability. In most projects regarding the design of fishing vessels, financial issues are the limiting factor. However, there is a growing focus on other sustainability issues, such as energy efficiency due to increasing fuel prices, safety due to the high accident risk, and emissions of greenhouse gases and acidification due to Norwegian commitments to the Kyoto Agreement and the Gothenburg Protocol. The article attempts to include such costs in the LCC analysis, even though there are problems, for example related to discounting and sustainability issues. Acidification may be weighted less and less into the future, which means that if discounting occurs, the less important the losses due to acidification will be. Thus, discounting gives a bias against future generations and may seem inconsistent with sustainability. The article suggests discounting these issues within the project's financing horizon.

The performance indicators use different measurements, such as economic value, fuel consumption (kg fuel/kg fish), and number of fatal accidents. If profitability increases and the fuel consumption decreases, it is difficult to quantify if this change contributes to increased or decreased sustainability. In the given example, profitability and emissions may be interlinked, as reduced fuel consumption leads to reduced fuel costs. However, there are other aspects to the emissions as well, such as issues regarding climate change and acidification; issues that do not affect the fishing vessel owner directly, but the society in general.

To determine the relative importance of the performance indicators is a matter of political priorities and stakeholder interests. Article 3 came about to show which aspects of sustainability different stakeholders emphasize, how prioritization or weighting may be carried out, and how the system performance is affected by doing trade-offs. The main conclusion of Article 3 is that sustainability is dependent on whose "glasses" one is wearing, and that the high number of fatal accidents regarding small fishing vessels is a serious implication when claiming that these vessels are the most sustainable.

One of the most difficult tasks when designing complex systems is to determine all the requirements, such as requirements to a sustainable fishing fleet. The attributes may be used as general aspects that the requirements to the system

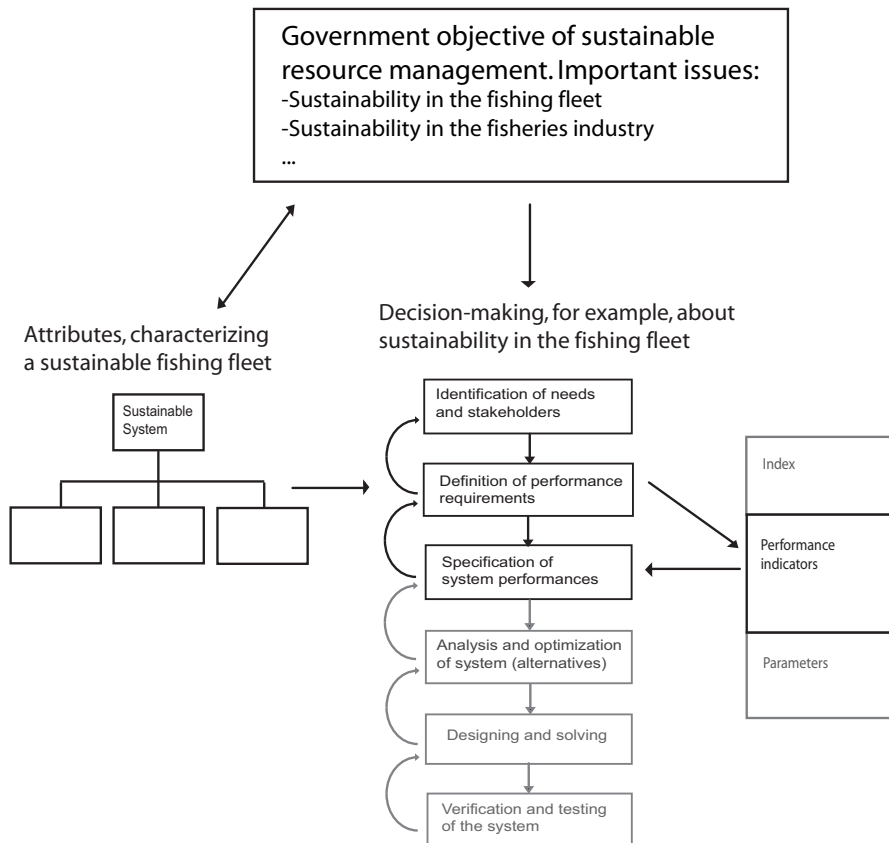


Fig. 5.3. The connection between attributes, requirements and indicators.

should reflect. The differences between attributes, requirements, and indicators are shown in Figure 5.3.

The performance indicators are used to evaluate the system, to give input to fisheries management about the effectiveness of its policies. Nevertheless, the measurements of the performance indicators give no information regarding when the system is sustainable. Questions like "is an annual average of 10 fatal accidents acceptable?" and "when is the fuel consumption in the fishing fleet sustainable?" are discussed in article 6. Design solutions to reduce the energy use are also discussed in terms of effectiveness. The results show that it will be difficult to achieve the necessary emission reductions in the fishing fleet according to Norway's commitments to international agreements.

Conclusions and further work

This chapter describes the main contributions of the thesis and suggests topics for further research.

6.1 Main conclusions

The main contributions of this thesis are:

- Development of a methodological framework that structures fisheries management decision-making, with main emphasis on improved sustainability in the fishing fleet.
- Clarification of the concept of sustainability in the Norwegian fishing fleet.
- Classification of attributes characterizing sustainability, and a performance evaluation of the different vessel groups in the cod-fishing fleet.
- Comparison of two cod-production systems, with focus on sustainability.
- Suggestions for how fisheries management can evaluate sustainability on a regular basis.
- Improved foundation for further research about sustainability in the fisheries. A lot of literature is collected and synthesized.

The results of this thesis may mainly be used by decision-makers in public administration, politicians, fisheries organizations, and others with interests in the same research field, to:

- Develop new rules and regulations related to sustainable fisheries.
- Enforce implementation of more sustainable technological solutions in the fishing fleet.
- Implement regular evaluations of the sustainability performance of the Norwegian fishing fleet.

Most research contributions regarding the fisheries are rooted in the disciplines of biology (using research vessels such as Jan Mayen, shown in Figure 6.1) and economics. Sustainability in the fisheries is dependent on multi-disciplinary

information, which means that, besides developing new and effective technological solutions, the engineering sciences should contribute to analyses of the effects of technology on sustainability at a macro-level.



Fig. 6.1. The ice-going research vessel Jan Mayen. Permission by the Norwegian Seafood Export Council. Photographer: Mikael Westh Hammer.

In general, the Norwegian fisheries management does not have clear and measurable requirements to sustainability. The interpretation of sustainability is dependent on the Minister of Fisheries and the political situation. The fishing fleet is exposed to many accidents, and there seems to be a “silent acceptance” by the fishers, as well as the authorities, that fishing is dangerous, has always been dangerous, and most likely will continue to be so. Hopefully, the results from this thesis may contribute to more focus on safety issues, which should be included in the management perspective on sustainability.

The traditional capture fishing of cod and the up-coming cod-farming industry have been evaluated to give input to fisheries management and fisheries organizations. Cod-farming should be seen as a complimentary business to the traditional fisheries, however, the cod-fisheries may have to face changes to the existing management system.

The thesis’ main objective: “To develop a framework that integrates a technological perspective into fisheries management in order to define, evaluate, and improve sustainability in the Norwegian fishing fleet.” is fulfilled. This thesis has also introduced some decision-making methods that could be used by fisheries management. Nevertheless, there is a need for practical implementation of these methods into fisheries management. Further work should concentrate on specific decision situations and evaluate the results from use of the systematic approach

suggested in this thesis. There is also a need for further research within the detailed objectives of the thesis, described in the next section.

6.2 Further work

The more specific objectives of the thesis were:

- To discuss and clarify the main concepts; sustainability, sustainable fishing fleet, and overcapacity.

This thesis has analyzed important aspects of these concepts. Fisheries management should define what a sustainable fishing fleet is, and how the performance of the fishing fleet should be measured in order to evaluate the effects of management decision-making.

- To identify technological, ecological, social, and economic factors that influence sustainability in the fishing fleet.

Further work should be carried out for other parts of the value chain. This thesis has focused on the fish catching phase, however, sustainability in the fisheries depends on the performance of, for example, the fish processing industry.

- To define and discuss indicators and acceptance criteria that can be used to measure and monitor sustainability in the fishing fleet.

The Directorate of the Fisheries publishes a lot of information about the Norwegian fisheries every year. This information is fragmented and it is difficult to assess the overall trends of the development in the fisheries. Further research should concentrate on structuring and simplifying the data from the Directorate, without losing important information.

- To analyze and compare sustainability between a Norwegian fishing fleet and another production system, for example the cod-fishing fleet and cod-farming.

The cod-farming industry is in its initial phase, however, cod-farming may equalize the salmon aquaculture industry in the future. Further research should work with issues regarding how cod-farming and cod-fishing could cooperate and fulfill the needs of the markets, to reduce possible conflicts between two competing production systems.

This thesis has also showed that the fishing fleet is a dangerous occupation, with much higher accident risk than other similar occupations. Further research should focus on efforts needed to reduce the number of accidents.

“Our society is often accused of selling its future generations short. In an attempt to ameliorate our immediate woes we often exacerbate our future problems. Analysts must constantly make trade offs between what is right for the present generation and what is right for future generations. Some think that we’re worse off today

than we were in the past and that this trend is likely to continue. Others feel that future generations will be better off than we are today and that it is reasonable to borrow from the future to improve the present. What obligations do we have to future generations? Should the future be given more weight just because there will be more people in the future than in the present? It seems that as our time perspective unfolds, our spatial concerns grow too: today and tomorrow, it is our family; in the decades ahead, it is our country; in the centuries ahead, it is the world's population; and in the millenia, it is the planet Earth" [94].

Acronyms

CBD	Convention on Biodiversity
CSD	UN Commission on Sustainable Development
FAO	Food and Agriculture Organization of the United Nations
FAR	Fatal Accident Rate
IEQ	Individual Effort Quotas
IQ	Individual Quotas
ITQ	Individual Transferable Quotas
LCC	Life Cycle Cost
MSY	Maximum Sustainable Yield
NGO	Non-Governmental Organizations
NTNU	The Norwegian University of Science and Technology
PH.D.	Doctor of Philosophy
Q	Quotas
SE	Systems Engineering
SINTEF	The Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology
TAC	Total Allowable Catch
UNEP	United Nations Environmental Programme
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
VQ	Vessel Quotas
WCED	World Commission on Environment and Development

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Part II

Articles

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Article 1

Systems engineering principles in fisheries management

Marine Policy, 2006, 30, p. 624-634

Systems engineering principles in fisheries management

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Abstract

Fisheries management receives valuable, but often fragmented information from academic disciplines such as biology, economics, and social sciences. A multi-disciplinary perspective seems to be necessary if the fisheries are to become sustainable. Globally, overcapacity is considered as the most serious threat to sustainable fisheries, which indicates the need for a stronger integration of technological aspects into fisheries management. This paper discusses application of systems engineering principles and integration of technology into fisheries management. The systems engineering process facilitates implementation of multi-disciplinary information from researchers to fisheries managers in the decision-making towards sustainable fisheries, but may also be used to overcome multi-disciplinary obstacles among scientists. The article concludes that use of systems engineering principles may become a valuable contribution to fisheries management because of increased transparency and reduced risk associated with the decision-making process.

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Keywords: Fisheries management; Sustainable fisheries; Technology

1. Introduction

Even though the main objective of fisheries management is to move towards sustainable fisheries [1,2], most efforts have failed. Management of some fish stocks is facing dysfunctional national and international cooperation, and available resources are decreasing [3–6]. Academic disciplines such as biology, economics, and social sciences provide valuable information to fisheries management. Still, the solutions they offer only solve parts of the complex problems the management is facing, as most of the solutions are limited to the discipline within which they are proposed. Individual transferable quotas (ITQ) may, for example, be considered as economic efficient by economists, marine protected areas (MPA) as ecosystem-friendly by biologists, and community based management (CBM) as a goal to social anthropologists. As Degnbol et al. [7] states: “Fisheries science must be pragmatic and open to perspectives, assumptions, insights and methodologies of all the disciplines as required in the specific case (...) Researchers of the relevant natural and social science disciplines must find ways to work out their differences and disagreements in order to convey a more coherent message

than the ones managers and users receive today”. An example of a non-coherent message is the conflicting perspectives of the concept of sustainable development. What may seem unsustainable for an environmentalist may be sustainable for an economist. Most often the interpretations are influenced by perspectives of the institutions or groups behind, and the word “sustainable” can mean almost anything [8].

If the fisheries are to become sustainable, it is necessary to address the fisheries systems from a multi-disciplinary perspective [7]. A multi-disciplinary approach to fisheries management is holistic and considers the ecological, social, and economic dimensions of sustainable fisheries. Technology can be considered as an agent to achieve sustainable development within these dimensions. For instance, the environmental burdens can be substantially reduced by choosing the right technologies [9].

Globally, overcapacity is considered as the most serious threat to sustainable fisheries [10]. The technological development in the fisheries increases fishing efficiency and catch capacity in spite of input controls (e.g., licenses), output controls (e.g., total catch quotas), and technical restrictions (e.g., time and area closures). A reduction of overcapacity is one step towards sustainable fisheries [11] and an important issue in this respect is whether the

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traditional management models are sufficient for monitoring the development of capacity [4] or whether the role of technology as a relevant discipline in fisheries management is underestimated.

Technical and social systems increase in their complexity and vulnerability, and human-made systems, such as the fisheries, are not in conformance with natural systems. Industrial ecology is a framework for organizing production and designing consumption systems in ways that resemble natural ecosystems to achieve a more efficient industrialization, adjusted to the tolerances of natural systems. Technology should work with natural systems, not against them [12]. In a natural system there is a causal relation between causes and their effects. The natural cause and effect relationships are the designer's advantage when human-made systems are being designed [13].

Closely related to industrial ecology is systems engineering, because industrial ecology focuses on systems thinking. Systems engineering is defined by The International Council on Systems Engineering (INCOSE) [14] as “an interdisciplinary approach and means to enable the realization of successful systems”. Systems engineering deals with analysis and design, operation, and maintenance of large integrated systems under a total life-cycle perspective. Technology, management, legal aspects, environmental and social issues, finances and corporate strategies are taken care of by a total system integration [15].

A system is defined by the ISO/IEC 15288 standard [16] as “a combination of interacting elements organized to achieve one or more stated purposes”. A system can be described as an organized and structured totality of parts, such as natural physical and biological systems, and for social, commercial, and political forms of organizations [13].

Systems engineering focuses on life-cycle design, because any system develops and operates in the course of time. The system configuration should be responsive to stakeholders' needs and to life-cycle outcomes. The heart of systems engineering is the systems engineering process, which is a holistic and systematic approach to the problem solving process. In the systems engineering process the professional knowledge and skills of the team members form the basis for their participation in the integrated teamwork of system design [17]. The systems engineering process is iterative, and expands on the common sense strategy of understanding a problem before solving it, examining alternative solutions, and verifying that the chosen solution is correct before implementing it [14]. The basic process tasks are [12,13]:

- identification of system stakeholders and needs;
- definition of performance requirements;
- specification of system performances;
- analysis and optimization of the system (alternatives);
- designing and solving;
- verification and testing of the system.

Further description of the systems engineering process may be found in [12,13,15,17].

The objective of this article is to discuss application of systems engineering principles in fisheries management, based on the need for an integration of input from biology, economy, social sciences, and technology. The systems engineering process facilitates integration of multi-disciplinary knowledge and information from the researchers to the fisheries managers in the decision-making towards sustainable fisheries, but may also be used by scientists to overcome multi-disciplinary obstacles. The article is structured by following the steps of the systems engineering process, and examples from the fisheries are used to illustrate the different steps. The article concludes that use of systems engineering principles may become a valuable contribution to fisheries management due to increased visibility and a reduction of the risks associated with the decision-making process.

2. Applying systems engineering principles to the fisheries

A systems engineering approach to the fisheries involves connecting and describing objects and events. A life-cycle orientation that addresses the various system phases, i.e., design and development, production, distribution, operation, maintenance, retirement and disposal, is emphasized. If a system is to be analyzed in a holistic manner, it is necessary to consider all system phases, and identify the most important of these. When considering the fisheries, there are several life cycles, e.g., the life cycles of the fleets, of the individual vessels, of the equipment onboard each vessel, and of the fish. The fish is influenced by the fisheries during its entire life cycle, by ecosystem disturbances, and by emissions from production and disposal of technologies. The main interaction between the fish and the fishing fleet is in the fishing fleets' operational phase.

It is common to divide systems into four main categories; hardware, software, bioware (or personnel), and economy. The hardware category is related to all physical parts of the system, i.e., parts that can be manufactured by means of technology, such as the fishing vessels. The software category is related to computer programs, instructions or general procedures, laws and regulations, and may be associated with information science and science of law. The bioware category is related to human elements; human interaction with the system, connected to social science. Publications on Actor-Network Theory in fisheries [6,18] are examples of research on human interaction within the fisheries. The economy category is related to monetary aspects, i.e., financial science. A system may be viewed as a combination of some or all of these categories [12]. The four system categories can be related to the economic, ecological, and social dimensions of sustainable fisheries.

Inputs from biologists are important to the fisheries management in order to optimize and design the best management system. The way the systems engineering principles are related to fisheries management in this article, means that fisheries management is the system to be analyzed, not the fish itself and the marine ecosystems.

The overexploitation of fish is the primary driver for the need for sustainable fisheries and a well-functioning management system. In this context, fish may be considered as part of the natural system interacting with the human-made system of the fisheries and fisheries management.

2.1. System boundaries

Inputs and outputs to the system may be defined as resources and information crossing the system boundaries. The system boundaries may be related to: geographic boundaries, the kind of processes utilized, e.g., extraction of resources, the types of byproducts, emissions, and determination of which interrelated systems belong to the system under study and which do not [12]. Defining system boundaries is important in order to be able to carry out a proper analysis.

2.2. Identification of system stakeholders and needs

To identify the stakeholders's needs, it is necessary to know who the stakeholders are. Mikalsen and Jentoft [19] base their discussion about stakeholders and stakeholder inclusion in fisheries management on the theory of Mitchell et al. [20] and classify stakeholders according to the attributes "power", "urgency" and "legitimacy". Clarkson [21] distinguishes between primary and secondary stakeholders based on their relationship to the area at "stake": a primary stakeholder is one that the system cannot survive without; a secondary stakeholder is one who influences or is influenced by the system, but is not essential for its survival.

In a systems engineering perspective, it is appropriate to divide the relevant stakeholders into primary, secondary, and tertiary stakeholders, according to their "distance" to the issue at stake. This distinction makes it easier to specify requirements to the fisheries management system later on in the process. If the focus is on the stakeholders' power or lack of power, a classification such as Mikalsen's and Jentoft's [19] may be applicable, but power should not be a decisive factor when evaluating the stakeholders' needs.

Table 1 shows the identified stakeholders. These are present in most fisheries. In this article, tertiary stakeholders are the stakeholders affected by the fisheries as a third party.

The primary stakeholders to the fisheries management system are the fishers and the ship owners (who can also be fishers), because there will be no fishing activity if there are no fishers. One could object to this and claim that the bureaucrats are the primary stakeholders as they enforce the management system. However, the management system is not constructed mainly to fulfill the bureaucrats' needs, and there would be fishing activity going on regardless of whether the management agencies exist or not.

The secondary stakeholders are those not directly affected by the catching process: the bureaucrats and

Table 1
Stakeholders to fisheries management

Stakeholders	Primary	Secondary	Tertiary
Fishers	x		
Equipment suppliers		x	
Bureaucrats		x	
Enforcement agencies		x	
Scientists			x
Ship owners	x		
Sector organizations		x	
Banks			x
Future generations			x
Fish processors	x		
Local communities		x	
Society			x

The configuration of the table may vary depending on type of fishery.

enforcement agencies, the equipment suppliers, sector organizations and the local communities. Fish processors are included because their need for stable deliveries of fish is influencing management decisions regarding the fleet structure. The tertiary stakeholders: the banks, scientists, the society as a whole, and future generations are included due to the financial impact on the fisheries from the banks, the scientists' research on the fisheries and their input to the management system, the interchange of goods and values in the society, and the future generation's perspective in the concept of sustainable fisheries.

When the stakeholders to the system are identified, their needs can be described. "Need" is a rather vague concept which can be interpreted in different ways, e.g., related to basal needs or every type of consumption [22]. The need analysis is connected to the desired performance of the system, because the needs reveal stakeholder expectations to the system. Whereas the needs are connected to the stakeholders, the desired performance is a projection of the needs into the system design. The actual performance of the system is evaluated through the iterative process of systems engineering, and the system design is adjusted so that the actual performance becomes close to the desired performance.

In this article, the needs of the stakeholders to the fisheries are related to the management objectives of sustainable fisheries; to fish as a commerce that provides economic benefits. Needs are therefore closely related to stakeholders.

Behind every need there is a reason, desire or a motivation. The need formulation in systems engineering is an answer to the question "what is needed?":

- To achieve sustainable fisheries so that future generations will be able to fulfill their need for fish.

The rationale formulation is an answer to the question "why is it needed?":

- The reason is that several fisheries today are not sustainable.

The search for the concept solution will answer the question “how may the need be satisfied?”:

- This may be done by developing a holistic fisheries management system that takes economic, ecological, social and technological aspects into considerations.

Behind the need analysis lies the assumption that a management system is necessary to achieve sustainable fisheries. The reason is that without adequate management of the fish resources, fishers have little incentive to conserve the fish stock as the benefits of doing so are likely to be profited by others, as in open access fisheries. Optimum use of the marine resources, the assets and the human resources applied to catching fish, is dependent on a proper management system [23].

2.3. Performance requirements

After the need analysis follows a translation of the needs into performance requirements, i.e., statements that describe how the system is supposed to function in order to meet the needs [15]. Functional requirements reflect the needs of the stakeholders related to the system’s ability to carry out a function, i.e., what the system does and how it is done. Operational requirements are related to the actions and functions that have to be carried out during the operation of the system, i.e., what the system does over time and how it is operated and manipulated. Physical requirements explain the needs for physical connections between the subsystem and elements, i.e., the physical conditions the system will be exposed to and how the system fits into the environment [12,15].

The overall performance requirement for the fisheries management system is that the fisheries should be managed in such a way that it becomes sustainable within the economic, ecological and social aspects. There are several

requirements that have to be fulfilled, derived from the stakeholders’ needs. Some of these requirements can be found in Table 2.

2.4. Specification of system performances

The requirements may be formulated qualitatively, but transforming them into specifications means making them more quantifiable and precise for the performance of the total system and its subsystems. A specification of a system is, according to Østerås et al. [24], a set of statements about a system derived during pre-development stage to achieve some desired performance. Verification of how the specifications actually meet the requirements is carried out during the test and evaluation phase of the systems engineering process [15].

Most fisheries systems can be decomposed into several subsystems, which again can be decomposed into lower level subsystems, and at last into system elements. The overall system performance is dependent on the performance of each element. Fig. 1 decomposes the Norwegian fisheries into the subsystems: the fishing fleets, the fish processing industry and the market. For simplification and illustration, the following discussion is focused on the fishing fleet.

The fishing fleet is a man-made, open, physical, and dynamic system operating in a natural system. The fishing fleet may be further divided into fishing vessels, which

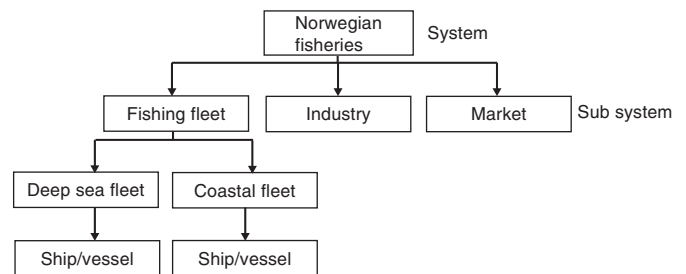


Fig. 1. System decomposition of the Norwegian fisheries.

Table 2

The connection between social, ecological and economic needs among the stakeholders and examples of functional (F), operational (O), and physical (P) requirements for the system

Social	Economic	Ecological
The system shall, during operation, give information on deviations in the acceptance criteria of sustainable fisheries (O)	The system shall ensure profitability in the fisheries (O)	The system shall prevent overexploitation of the fish stocks (O)
The system shall reduce the accident risk level for the fishers (O)	The system shall make the fishing fleets capable of fishing x tons fish per year (F)	The system shall promote reduction of by-catch (O)
The system shall enforce regulations to protect the fish stocks (O)	The system shall not be too costly to operate (O)	The system shall promote use of technology that reduces the environmental impact (O)
The system shall ensure stakeholder inclusion (P)	The system shall not be too costly to implement (F)	The system shall reduce overcapacity (O)

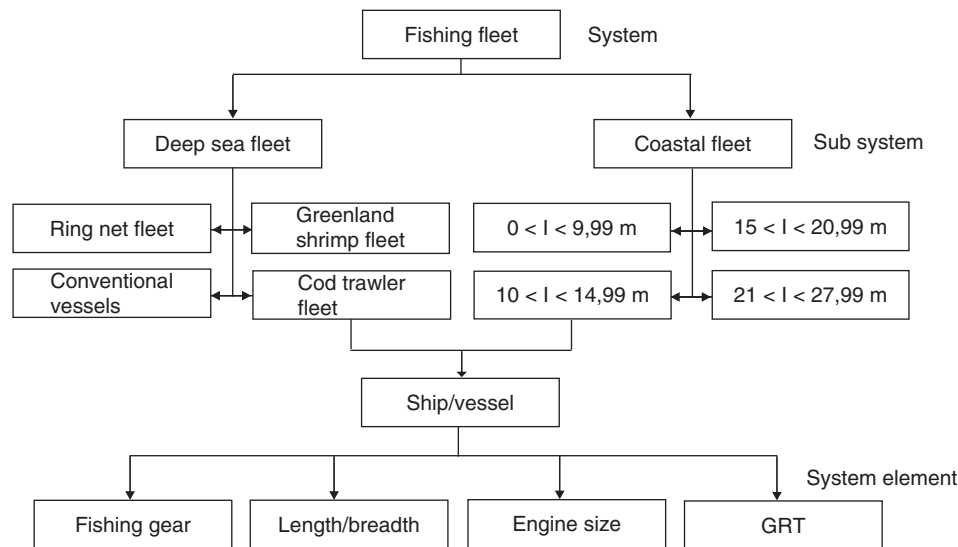


Fig. 2. System decomposition with respect to technical capacity.

again may be decomposed into subsystems and system elements depending on the vessel design and equipment. It is difficult to make a clear distinction between vessels belonging to the deep sea fleet and the coastal fleet. The technological development and operational patterns change. The decomposition in Fig. 2 is based on [25] and [4]. The system elements are based on the technical capacity parameters as discussed by Standal [4].

Standal [4] uses vessel design and technical properties of vessel equipment: basic dimensions such as length/breadth proportion, overall mobility of a vessel, size of the main engine, and a fishing gear indicator to describe the capacity development in the Norwegian fisheries fleet. By an individual weighting of the technical parameters, basing the fishing gear indicator on the number of trawls and the resulting efficiency increase, Standal [4] is able to calculate the increase of the technical capacity in the shrimp trawler fleet from 1988 to 2002. Standal [4] also shows that there has been an increase in the catch capacity in other gear and vessel groups, even though the number of vessels has been reduced in accordance with government objectives.

The advantage of doing a decomposition is that even though the problem at hand may only require detailed analysis of a few system elements, it makes it possible to see the elements' relationship to other parts of the system and thus get an overview of how the system works. For the fisheries management the objective of developing performance specifications is not to design the optimal fishing vessel. However, when e.g., technical restrictions are introduced, it is important to know how such restrictions will affect the performance of the vessels and the fleets with respect to sustainability. Another advantage is the possibility to analyze differences within the fleet and between the fleets, i.e., the differences in performance with respect to stated objectives of sustainability.

2.5. Integrating performance indicators into sustainable fisheries management

Performance of the fisheries may be measured by establishing performance indicators. The definition of an indicator (I) in this article is influenced by risk management:

- An indicator is a measurable/operational variable that can be used to describe the condition of a broader phenomenon or aspect of reality [26].

Quantification of indicators may be carried out by using parameters (P), where $\mathbf{I}(t) = (P_1(t), P_2(t), \dots, P_n(t))$. A parameter can be defined as [26]:

- The variables in the framework for which numerical values are assigned. A variable can be a property that changes.

The purpose of using indicators is to simplify complex phenomena and relationships [22]. Indicators must be scientifically valid and utilize the “best scientific information available”. Indicators should also be feasible and cost-effective in terms of their information collection demands [11]. Performance indicators should enable measurement of performance towards management objectives and at the same time be comprehensible for potential users and stakeholders.

An index, $f(\mathbf{I}(t))$, is defined as [22]:

- An index is an aggregated function of the indicators showing the overall system performance.

Indices, indicators, system alternatives, and parameters form a “hierarchy”. An index can be used in different circumstances, i.e., price index.

Thus, indicators are based on the parameters whereas indices are made up by indicators. If the objective of the analysis is related to overcapacity issues, the different system alternatives may be the subsystems shown in Fig. 2 whose properties are based on parameter values (the system elements from Fig.2). These parameters vary with different vessels and gear groups accordingly.

By measuring the performance indicators annually, as illustrated in Fig. 3, it may be possible to find out if the catch capacity in a certain fishing fleet develops in a sustainable direction. It would be possible to measure a capacity index, $f(I(t))$, for a specific fleet, but also aggregate all capacity indices of different fleets into one index of the total capacity of the entire Norwegian fishing fleet. Such an aggregation would imply weighting and normalization of the indicators and introduce a range of uncertainty to the total index, depending on the amount of aggregation.

Several indices and indicators exist already, some of which may be difficult to implement to fisheries management due to the amount of information needed for updating [11]. Others show only a very limited part of the total situation [27]. Examples of relevant performance indicators to fisheries can be found in Table 3.

The technological development within the fisheries fleet leads to environmental problems, i.e., increased engine size leads to increased emissions of greenhouse gases. It may be more difficult to measure the exact amount of greenhouse gas emissions than increased average breadth of the fishing vessels; at least such figures cannot be calculated without introducing uncertainty. Since reduction of overcapacity in the fisheries fleet is in accordance with management objectives of achieving sustainable fisheries, and since overcapacity is related to technical parameters of fishing vessels, as discussed by Standal [4], then frequent measurement of performance indicators based on technical parameters (Table 3), would be a valuable contribution to the achievement of sustainable fisheries.

Indicators and indices have limited utility without pre-determined acceptance criteria. The acceptance criteria are related to tolerability, and should be measurable. In the case of the capacity development, the tolerability is related

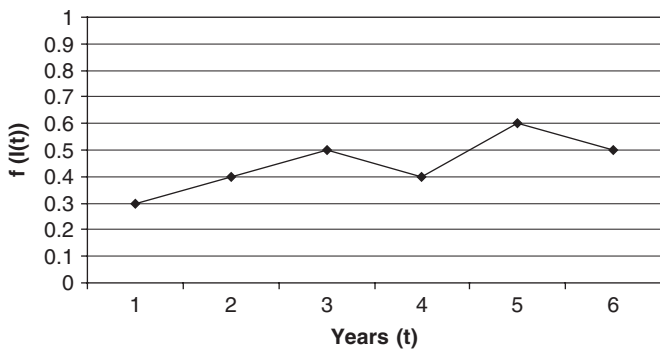


Fig. 3. Using an index to monitor the sustainable development in the fisheries.

Table 3

Examples of performance indicators that may be used in fisheries management to evaluate the fisheries

<i>Indices</i>	
Fish resources	(intensity of exploitation of fish stocks)
Climate change	
Human health impact	(impact on human health and safety)
Catch capacity	(aggregated measure of capacity indicators for a fleet)
Employment	
Profitability	
<i>Performance indicators</i>	
Emission of CO ₂ /kg fish	
Fuel consumption kg/kg fish	
Capital costs/kg fish landed	
No. of employees	
Risk, casualties per 10 ⁸ working hours (FAR)	
Catch capacity	(aggregated measure of the capacity parameters for a vessel)
Quota deviation	= Total allowable catch-Recommended catch
<i>System alternatives</i>	
Vessels A and B	
Fleets A and B	
<i>Parameters</i>	
Fuel consumption (kg)	
GRT	
Length	
Total catch fleet	
Size of main engine (hp)	
Breadth	
No. of accidents	
Economic data	

Based on [3,4,11,12,27,28].

to a sustainable capacity level of the fisheries fleet. It may be difficult to define a tolerability level of capacity, but the overcapacity in the fisheries fleet is not only environmentally unsound. The most direct effect for the fishers is the economic profitability, which turns out low and not sustainable as the catch capacity increases without an increase in available target species. Thus, overcapacity can be estimated both economically and technically [29].

Retrospective performance indicators are based on measurable events in the past. If the objective is to find out how new regulations will affect future technological development of vessels or how the fuel prices will affect the fisheries fleets' profitability, prospective performance indicators are required. Prospective performance indicators are predictive because their objective is to give a warning of undesired consequences, as a "trend analysis".

Selection and weighting of performance indicators, require trade-off decisions regarding which aspects of sustainability are more important than others. Trade-off analysis is discussed in the next section.

2.6. Analyze and optimize

Different system alternatives will give advantages and disadvantages, and this also applies to management

systems. Fisheries management faces several challenges and contradictory demands from many stakeholders. Management decisions will impact a range of stakeholders with interests in the fisheries. A holistic management system requires all types of advantages and disadvantages to be taken into account and evaluated [30].

Conflicting situations may occur between the different system requirements, i.e., a system of ITQ may reduce overcapacity, but also lead to increased concentration of quotas [7]. One type of fishing technology may give higher income, but fewer employees and increased emission of CO₂. Optimization is used to determine the best combination of management actions that provide the best way of achieving the desired system performance. Optimization may be performed by using system analysis and trade-offs in an iterative loop until the best solution is found. This process is illustrated in Fig. 4.

Trade-off analysis may be done qualitatively or quantitatively or both. In a qualitative assessment the performance specifications may be ranked based on information from the stakeholders and the objective of the analysis [12]. In a quantitative assessment, the performance specifica-

tions have to be measurable. Performance indicators can be used as a starting point [12]. In a simple quantitative approach, the specifications may be expressed by using a common unit such as currency, and then the combination that maximizes the value is selected. With a large number of specifications, as in fisheries management, a single optimal solution is not likely. However, by carrying out trade-off analysis, the compromises become explicit rather than implicit [3].

Table 4 shows the impact from three management alternatives of effort control on some performance indicators of a fishery. The pluses and minuses summarize how each method is likely to affect the performance of the fishery, compared to the period before it was introduced [3]. There are different ways of ranking and evaluating these alternatives, and the method in this example is qualitative, with no internal ranking. A more precise ranking would be to scale the impact from the effort control methods numerically. When selecting a preferred alternative from a potentially infinite set of alternatives, multi-criteria decision analyses (MCDM) may be used. There are numerous MCDM methods, ranging from very simple and straightforward models to advanced mathematical approaches that require computer calculations [31].

If the performance indicators in Table 4 are of equal importance, that means, they are weighted equally, and the objective is to reduce catch capacity and administrative costs, increase safety, employment, and profitability, a simple addition of pluses and minuses of the alternatives would result in selection of alternatives 1 and 2. The example in Table 4 is a simplification of management alternatives, because all three alternatives may be combined. A relevant extension of the decision problem in Table 4 would be an evaluation of the three alternatives in combination, and not only individually as shown here. Another discussion is the fact that effort controls used independently in fisheries are unlikely to provide a basis for meeting management objectives. A MCDM problem could therefore be to evaluate effort control alternatives in combination with technical measures and catch control methods [3].

The main purpose of the trade-off example in Table 4 is not to discuss what the weight factors or the acceptance criteria should be, but to illustrate how a trade-off analysis might be done. Weighting of different indicators is a task

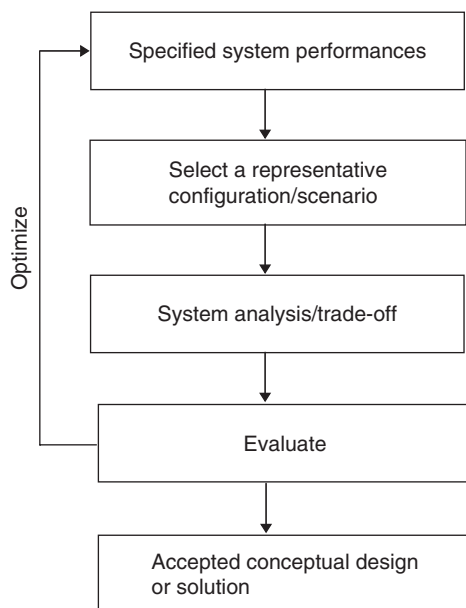


Fig. 4. The process of analyzing and optimizing [12,15].

Table 4
Example of impact on some performance indicators from three methods of effort control of a fishery

Performance indicators	Alternative 1: licenses	Alternative 2: individual effort quotas (IEQ)	Alternative 3: vessel/gear restrictions
Catch capacity	+	+	–
Safety (FAR)	–	+	–
Employment	+	–	–
Profitability of fishery	–	–	–
Administrative costs	+	+	+

Based on [3,32].

with uncertainty, and there is no final solution. Weighting may be carried out by using expert judgements, but also by evaluating the different scenarios wherein the system is to perform. Such scenarios intend to describe the potential negative (or positive) effects on sustainable development within the fisheries, based on the variations of the prospective performance indicators that should be measured regularly. Knowledge of the potential consequences is necessary to maneuver correctly, because ignorance may lead to misunderstanding of the signals received [33].

In order to find the most relevant indicators for the system alternatives and further select them for trade-off analysis, influencing causes and effects are important to determine. In the following, use of influence diagrams is briefly discussed as an adequate tool for explicitly showing the causes and effects of influencing factors or variables in the fisheries.

2.7. Influence diagrams

Influence diagrams are effective means for communication between decision makers, because they facilitate formulation, assessment, and evaluation of decision problems [34]. In fisheries management it is necessary to consider a range of potential decision alternatives and their possible consequences, and to implement management strategies that lead to sustainable fisheries. At the same time, stakeholder participation in the process has to be achieved. Influence diagrams are already applied in the fields of medicine, artificial intelligence, environmental issues [30], in maintenance modeling [35], and safety studies [36].

An influence diagram consists of a series of nodes which represent variables that interact with each others. The interactions are illustrated by arrows, which can be evaluated qualitatively by using different thicknesses of the arrows (the thicker arrow, the stronger relationship or influence [36]) or quantitatively by assigning probabilistic dependencies to the nodes through a set of conditional probability tables (CPT) [30]. Linking all variables affected by a particular decision in a quantitative way, is a complex task, because the variables may have different units of measurement, and some may also be qualitative in nature. When one variable is affected, this may impact on another variable, which again may affect other variables, and so on.

The diagram in Fig. 5 shows dependencies that are considered to be relevant for utilization of capacity in a Norwegian trawler fleet, at two different points in time, $t = t_1$ and $t = t_2$. If other dependencies are found meaningful by stakeholders, the model may be modified with appropriate arrows. The diagram demonstrates the relationship between the various measures of system performance, and external events. The diagram shows the technical parameters influencing the fleet capacity, meaning that the technical parameters represent measures of a vessel’s catch capacity. External events influencing the technical parameters or the fleet capacity in general, are not considered in the diagram.

A node representing the variable “costs”, as in Fig. 5, will be linked to a number of “parent” nodes, e.g., “fleet capacity” which includes the technical parameters “engine size,” “GRT” etc. on which it is dependent. For each variable, the CPT expresses the probability of that variable

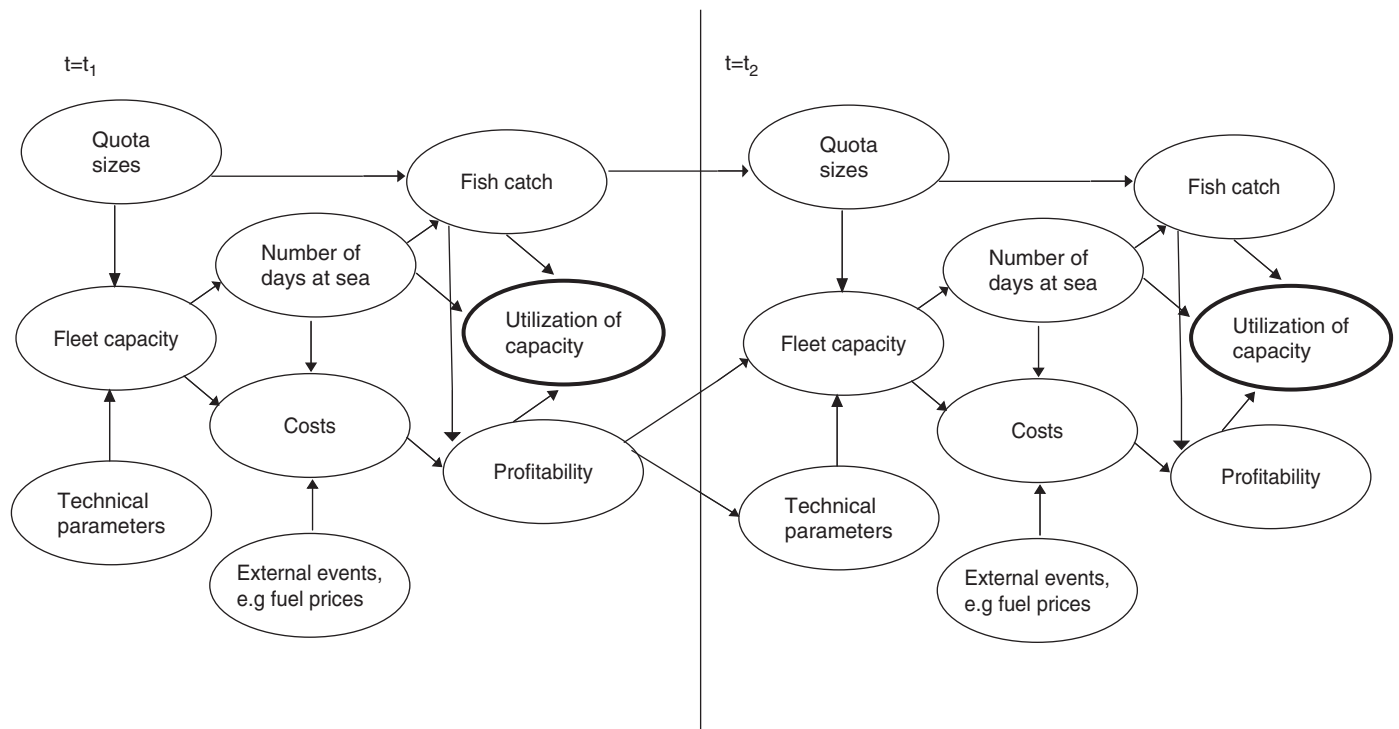


Fig. 5. A simple influence diagram showing variables relevant to utilization of capacity in a fishery at time $t = t_1$ and $t = t_2$.

being in a particular state, given the states of its parents. CPTs are constructed for each variable, and are based on the best information available. Such information may come from historical data, i.e., of fuel price change, or by using output from models, or when data available is limited; by using expert opinion [37]. For instance, a reduction of fish catch from one year to another may affect the fish population, and this relationship can be established through bio-economic models [3]. Further information about influence diagrams may be found in [30,34,35].

2.8. Design and solve

Designing a new system or adjusting an existing one, demands well defined performance specifications based on the needs and the desired performance identified in the earlier steps of the systems engineering process. The results from the trade-off analysis may show that one system alternative fulfills the system requirements better than other system alternatives. Designing and problem solving is an iterative process, and decision evaluation is needed in order to choose between the different alternatives [17]. The results of such analyses are dependent on system boundaries and the requirements set.

2.9. Verify and test

The final step in the systems engineering process is verification and testing. The evaluation of the results of the testing must be measured against the functional, operational, and physical requirements formulated earlier in the process. If the system does not meet these requirements, it has to be redesigned. The test and evaluation is another loop in the system analysis, as illustrated in Fig. 6.

Evaluation and testing is often difficult to carry out because the system design problems may occur in the future. In the fisheries, management decisions may have extensive consequences for human life and ecosystems. Testing of one management option in a fishery may not be easy, but may give the most reliable results.

While testing a management option in real life is not possible, one solution may be to compare data and relationships of the new system to previous experience [12]. At early stages in the system analysis, the evaluation

may be done qualitatively by using experts' judgements. Later on in the process, modeling and simulation programs and methods may be used, such as Monte Carlo simulation. A Monte Carlo simulation can be run to obtain a distribution for a predicted outcome. Given a clearly stated objective, Monte Carlo simulations can be done to evaluate relative performances of proposed management options [38].

When empirical evaluation of a prediction model is impossible to carry out, an alternative is to prescribe an ideal design process that may reveal the weakness of the model. A systematic approach would ensure accuracy, correctness, thoroughness, traceability, stringency, and order of the original method. If the method is inefficient or contains illogical conclusions, they are likely to be discovered when the empirical design is constructed [39].

3. Discussion

This article provides new ideas and solutions that may contribute to making fisheries management more sustainable. In systems engineering, information from different scientific disciplines, e.g., biology, social sciences, economy, and technology, are necessary input to the analyses and decision processes. Most fisheries scientists have concentrated on biological and economic assessment of fisheries, which often include mathematical modeling of how an exploited species will respond to different management options, or how profit should be maximized. However, fisheries management is much more than bio-economics, and systems engineering and industrial ecology offers a broader analytical perspective to fisheries management. The problem of overcapacity, which is strongly related to the technological development of the fisheries fleets, indicates that the technological aspect should be more strongly integrated into fisheries management than it is presently. Application of the systems engineering process in fisheries management and the inclusion of technology introduce new perspectives, new disciplines, and new stakeholders into the decision-making process in the fisheries.

Implementation of industrial ecology into fisheries management brings system thinking in ecology together with systems engineering and economics. The systems engineering method mainly uses the top-down approach, based on the point of view that the whole is more than just the sum of its parts. One of the most important attributes of systems engineering is the continuous evaluation process. As the system is analyzed, it is also evaluated at the different life-cycle stages in order to improve the system through the whole process. A potential benefit from implementing systems engineering into fisheries management is more transparency and a reduction of the risks associated with the decision-making process. Increased visibility is provided through the perspective on the system from a long-term and life-cycle perspective.

The desired performance of fisheries management can be related to system requirements. The overall management

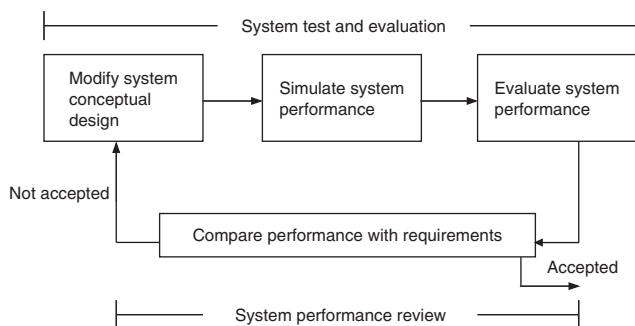


Fig. 6. Iterative test and evaluation based on [15].

objective is to achieve sustainable fisheries management, which is an overall requirement to the system as well. Management strategies can be based on the system performance specification, whereas analyzing and optimizing the performance specifications is related to management actions. The actions taken should be based on the strategies, and the strategies should be based on the objectives. Systems engineering is a holistic process, where management objectives, strategies and actions are systematically developed, based on the stakeholders' needs.

4. Further work

The problem that has been discussed in this article is very complex. What remains, is to apply systems engineering principles to specific decision problems in fisheries management, and to assess the consequences on institutions and stakeholders in the fisheries. An implementation can be seen as part of further development and adaptation of the systems engineering methodology related to fisheries management.

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Article 2

System evaluation of sustainability in the Norwegian cod-fisheries

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System evaluation of sustainability in the Norwegian cod-fisheries

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Abstract

Overcapacity in the fishing fleets is considered as the most serious threat to sustainable fisheries. More effective fishing vessels and catching gear contribute to increased catch capacity. Increased catch capacity causes environmental problems such as overexploitation and calls for larger quotas. The problem of overcapacity indicates the need for a stronger integration of technological aspects into fisheries management. This article assesses the differences in sustainability between the Norwegian ocean and coastal fishing fleets in the cod fisheries, by using systems engineering methods. Attributes of sustainability in the Norwegian cod fishing fleets are investigated, as well as acceptance criteria and performance indicators. The results show that there are huge differences in the performance between the vessel groups, and that the results of an evaluation of sustainability in the fishing fleets are dependent on which attributes are explored. Thus, the discussion may contribute to a better decision basis and improved sustainability in fisheries management.

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Keywords: Sustainable fisheries management; Performance indicators; Systems engineering

1. Introduction

Sustainable management of the fish resources is an important objective in Norway [1]. Overcapacity in the fishing fleets is a major threat to sustainable development [2], because it leads to increased pressure on fish resources, less profitability, and environmental problems such as greenhouse gas emissions from fuel consumption. In Norway, the fisheries policy after World War II has been influenced by technological modernization processes and institutional changes. The technological developments adopted, such as automatic hauling of purse seine in pelagic fisheries, the development of modern stern trawling, and automatic baiting in line fishing, have led to an extensive increase in catch capacity in the fishing fleets. Institutional measures of modern resource management models, such as total allowable catch (TAC), vessel quotas (VQ), limited access, and structural measures to reduce the number of fishers and vessels to increase profitability, have not reduced the problem of overcapacity [3,4].

The problem of overcapacity indicates a stronger integration of technological perspectives into fisheries

management [3]. Systems engineering has been introduced as a multi-disciplinary approach to sustainable fisheries management that may give increased visibility and a reduction of risks in the decision-making process [5]. The Norwegian fisheries management lacks frequent evaluations of its policies. In the systems engineering process it is important to specify and evaluate the system performances based on the requirements to the system. Evaluation of the performances may be carried out by using performance indicators, of which some were proposed in [5], and further discussed in this article.

Sustainability is a concept with various interpretations that, e.g., appear in discussions about what kind of fishing vessels are sustainable [6]. In Norway, there seems to be a consensus among non-governmental organizations (NGOs) and some political parties that the small conventional vessels are more sustainable than the large trawlers [7]. Since the concept “sustainable” is vague, the attributes used to assess the various vessel groups are very important, because some attributes may favour one vessel group at the expense of others. Thus, the main objective of this article is to evaluate the performance of the Norwegian cod fishing vessels with respect to sustainability.

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The first part of the article discusses attributes of sustainable fisheries related to the Norwegian cod fisheries. Performance indicators are evaluated, and acceptance criteria are described. The second part of the analysis compares different cod fishing vessel groups with respect to the selected attributes in part one, and cost/benefit assessments are discussed. The article shows that there are huge differences in the performance of the vessel groups with respect to sustainability, and that the results from an evaluation of sustainability are dependent on which attributes are explored. Thus, this discussion may contribute to a better decision basis and improved sustainability in fisheries management.

1.1. *The cod fisheries in northern Norway*

The ocean off the northern coast of Norway holds some of the most abundant fish resources in the world, e.g., the cod fishery being the most valuable Norwegian fishery with 39% of the total catch value of all fish species [8]. The most important species in the cod fisheries are cod, haddock, turbot, saithe, and two species of red fish [9]. The fleet fishing for cod comprises different types of vessels of various sizes, gears, and ways of handling the fish. In 2006, the Norwegian part of the TAC for the cod fisheries north of 62°N is 212 700 ton. Thirty percent is allocated to the trawlers and 70% to the conventional vessels [10].

In this article, the vessels are classified according to the following categories (ℓ denotes the length of the vessel):

- A: Small coastal vessels (net, hand line, Danish seine, long-lining), $\ell < 15$ m.
- B: Medium coastal vessels (except trawlers), $\ell = 15–27,9$ m.
- C: Large conventional vessels (long-lining), $\ell > 28$ m.
- D: Factory trawlers, possibly combined with shrimp trawling.
- E: Cod trawlers, possibly combined with shrimp trawling.

These categories are in accordance with the vessel groups in the cod fisheries in the statistics made by the Directorate of the Fisheries in Norway from 2003 and onwards.

2. Sustainable fisheries

Sustainable use of renewable resources is a widely accepted goal [11], and it is the main objective of the Norwegian fisheries management [12]. Thus, the concept of sustainable fisheries has to be clarified. Since “Our Common Future” [13] was published, several definitions and interpretations linked to the concepts of sustainability and sustainable development have been proposed. Operationalizing the concept of sustainable fisheries means to relate the concept to a specific political, cultural, and resource situation [14]. Different perspectives on sustainability appear when the stakeholders to the fisheries and their needs are analysed [5], and the conflicting views cause difficulties in achieving sustainable use of resources [11].

Sustainability cannot be investigated within the limits of a single scientific discipline, because it involves several disciplines, such as ecology, economy, engineering, law, physics, politics, and sociology. This multi-disciplinarity introduces cross-disciplinary communication problems that causes conceptual difficulties and unclear measures of sustainability [15]. As such, systems engineering may be a suitable process for handling sustainability issues [5]. The scientific disciplines may be reflected in the three dimensions of sustainable development: the environmental, social, and economic dimensions.

The environmental dimension involves exploitation of the fisheries with a long term perspective in mind, which means that future generations also must be able to fulfil their needs for fish. The precautionary principle, nature’s carrying capacity, and maximum sustainable yield (MSY) are concepts related to the environmental dimension [16]. “Carrying capacity” is according to the World Business Council on Sustainable Development (WBCSD) the ability of the earth to carry withdrawal and displacement of materials [17]. MSY is the largest catches that can be caught without causing the stock to collapse [4]. The precautionary principle is a disputed issue, but Principle 15 of the Rio Declaration of the UN Conference on Environment and Development in 1992 [18] states that “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall be not used as a reason for postponing cost-effective measures to prevent environmental degradation”.

According to FAO Code of Conduct for Responsible Fisheries, Article 6.5 [19] the “States and subregional and regional fisheries management organizations should apply a precautionary approach widely to conservation, management and exploitation of living aquatic resources in order to protect them and preserve the aquatic environment, taking account of the best scientific evidence available. The absence of adequate scientific information should not be used as a reason for postponing or failing to take measures to conserve target species, associated or dependent species and non-target species and their environment”. Key concepts have been the burden of proof (i.e., the responsibility for providing relevant evidence) and the standard of proof (i.e., the criteria to be used to judge that evidence) [20].

An analogy to the application of the precautionary principle may be drawn to the differing standards of proof used in civil and criminal law. Variations in the burden of proof on whether to carry out an action or not, may involve an analysis of the costs, benefits, risks and consequences of the action. Sustainability implies an ethical dimension, as the action may impact future generations [21]. The precautionary principle is incorporated into the management of the Norwegian fish resources, as a precautionary approach, which means that the degree of uncertainty in a stock assessment should determine the extent of exploitation [22].

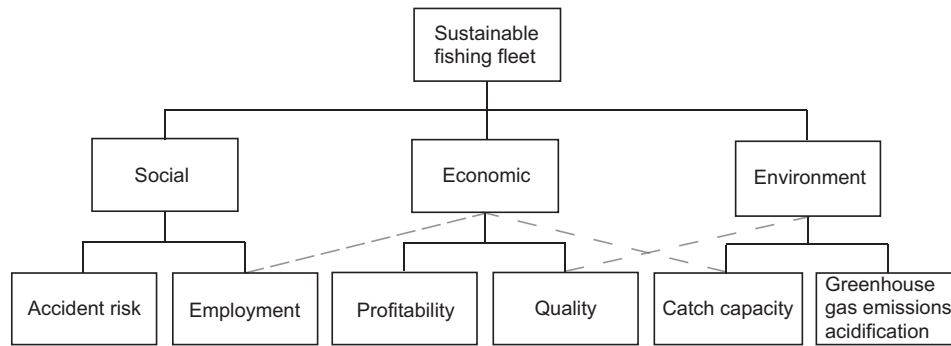


Fig. 1. Dimensions and attributes of sustainability in the Norwegian fishing fleet. The dashed lines indicate that the division is not absolute.

Fishing contributes to human welfare by fulfilling needs for employment and income, cultural needs and recreation [23]. These aspects are captured in the social dimension of sustainability, which also includes human rights, moral and justice [24]. The fisheries politics should be based on democratic principles, such as stakeholder inclusion and distribution of power [14]. Safety is another important aspect of the social dimension of sustainability, because accidents cause grief, stress and loss of social security. Statistics of the fisheries show that the profession is one of the most dangerous. The high accident risk affects new requirement, as young people may have other expectations and demands than the old fishers. The high accident rate is also an economic problem; skilled employees disappear, and insurance costs are high [25].

The economic dimension of sustainable fisheries is related to maintenance of human-made capital. This may involve the controversial concept of sustainable growth. Damage caused by the catching process and the handling of the fish onboard the vessels, influences the quality of the fish meat. Such damage may reduce the price paid for the fish and cause income loss [26].

Thus, a sustainable Norwegian fishery should be exercised without causing unwanted changes to nature's biological and economic productivity, the biological diversity or ecosystem structure from one generation to another. It should be exercised without a disproportionate consumption of non-renewable resources, and without challenging nature's carrying capacity. The authorities and the scientific community should base their recommendations and decisions on the precautionary principle. The fisheries should be exercised and managed so that social structures, knowledge and traditions are secured, and stakeholders are heard [14]. The fisheries should also be profitable, a safe workplace, and be an attractive way of making a living.

There are several attributes that may be used to describe sustainability in the fisheries, depending on how the system boundaries are defined. Since the main problem addressed in this article is overcapacity, the system boundaries are limited to the fishing fleet and the vessels in their operational phase. This means that the marine ecosystem in where the fishing vessels are interacting, is outside the

boundaries. Based on the former discussion of sustainable fisheries, the selected attributes of a fishing fleet are shown in Fig. 1.

3. Performance indicators for monitoring sustainability in the Norwegian cod fisheries

Table 1 lists six indicators, $I_{1,\theta}, I_{2,\theta}, \dots, I_{6,\theta}$, that can be used to measure the performance of system alternative θ of the fishing fleet, for $\theta = A, B, \dots, E$. The six performance indicators have been defined to cover the main attributes of sustainability. The attribute greenhouse gas emissions/acidification is, for example, represented by fuel consumption ($I_{6,\theta}$). If the indicators are measured at regular time intervals, they can reveal whether or not the fishing fleet is developing in a sustainable direction. A general discussion of performance indicators related to sustainable development in fisheries may be found in [5].

Let $I_{j,\theta}(t)$ denote indicator j for system alternative θ at time t , for $j = 1, 2, \dots, k$ and $\theta = A, B, \dots, E$ (In Table 1 $k = 6$).

Further, let $\mathbf{I}_\theta(t) = (I_{1,\theta}(t), I_{2,\theta}(t), \dots, I_{k,\theta}(t))$ be the vector of the k indicators for system alternative θ at time t . The overall performance of system alternative θ at time t of the fisheries may now be expressed as a function of the k indicators, as $f_\theta(\mathbf{I}_\theta(t))$, for $\theta = A, B, \dots, E$. The function $f_\theta(\mathbf{I}_\theta(t))$ is referred to as a sustainability index, $\eta_\theta(t)$, for system alternative θ at time t .

The sustainability index is an aggregation of the information measured by the indicators. The function $f_\theta(\cdot)$ may be adapted to represent the importance of the various attributes for system alternative θ . The simplest form will be to let $f_\theta(\cdot)$ be a weighted sum of the individual indicators, such that

$$\eta_\theta(t) = f_\theta(\mathbf{I}_\theta(t)) = \sum_{j=1}^k w_{j,\theta} \cdot I_{j,\theta}(t)$$

for $\theta = A, B, \dots, E$. (1)

Note that the function $f_\theta(\cdot)$ depends on θ , and hence that we may give different weights $w_{j,\theta}$ for the different system alternatives. An example would be if employment in northern Norway for vessel group A is considered to be

Table 1

Performance indicators that may be used in fisheries management to evaluate the Norwegian cod fisheries, related to the sustainability attributes

Performance indicators	System alternatives (θ)				
	A	B	C	D	E
$I_{1,\theta}$ (fatalities per 10^8 working hours, FAR)	.	.	.	.	.
$I_{2,\theta}$ (average no. of man–labour years/vessel)	.	.	.	.	.
$I_{3,\theta}$ (earning capacity, NOK/ kg fish catch)	.	.	.	.	.
$I_{4,\theta}$ (income loss due to damaged fish, NOK)	.	.	.	.	.
$I_{5,\theta}$ (catch capacity, aggregated measure of the vessel capacity parameters [3])	.	.	.	.	.
$I_{6,\theta}$ (fuel kg/kg fish)	.	.	.	.	.
Aggregation and weighting	Score	Score	Score	Score	Score
Sustainability index, $f_\theta(\mathbf{I}_\theta(t))$	$f_A(\mathbf{I}_A(t))$	$f_B(\mathbf{I}_B(t))$	$f_C(\mathbf{I}_C(t))$	$f_D(\mathbf{I}_D(t))$	$f_E(\mathbf{I}_E(t))$

more important than employment in southern Norway for vessel group D.

If we are able to quantify the sustainability indices in Eq. (1), we may use them to compare the system alternatives A, B, . . . , E, with respect to sustainability at a specified time t . We may also plot the indices as a function of time and study how they “respond” to changes in quotas, management decisions, and so forth. The indices for each system alternative may also be aggregated into a total index, Eq. (2), to evaluate the sustainability for the whole fishing fleet.

$$\eta(t) = \sum_{\theta=A}^E a_\theta(t) \cdot \eta_\theta(t) \quad \text{for } \theta = A, B, \dots, E. \quad (2)$$

The system alternatives may be given weights, $a_\theta(t)$, that represent the fleet structure at time t .

There are several challenges related to using the indices, as the weighting and normalization of the indicators introduce a range of uncertainty and ambiguity into the total index, depending on the amount of aggregation. Selection and weighting of performance indicators require trade-off decisions regarding which attributes of sustainability are more important than others [5].

3.1. Establishing acceptance criteria of sustainability for the fisheries

To interpret changes in the performance indicators, reference values or acceptance criteria, that are either objectives or limits to be avoided, should be determined. The reference levels may be established by considering past performance of the system or from using mathematical models that indicate how the system should be expected to perform [23]. Acceptance criteria are commonly used in, e.g., risk management to express the tolerable risk level in a specific time period or of an activity. Risk acceptance criteria may be used as a reference point when assessing the need for risk-reducing efforts [27].

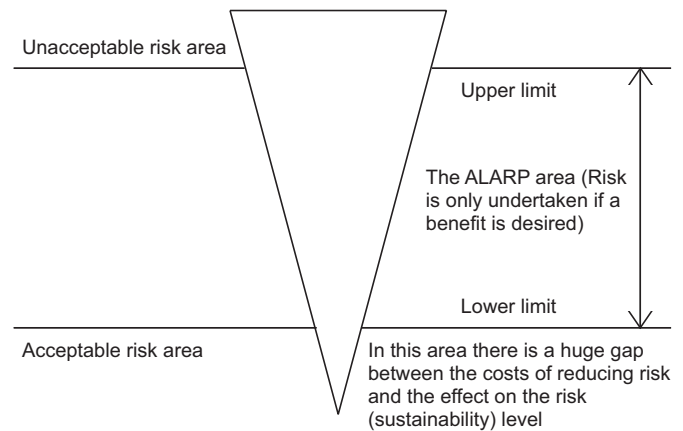


Fig. 2. The ALARP principle. From the Norsok Standard Z-013N [27,51].

Risk and sustainability may be seen as complementary concepts [28]. Sustainable development in the fisheries means to establish a system that fulfills the needs for fish for present and future generations. Such a system should prevent hazards that may threaten the sustainability. Risk management is a tool that may be used to measure and reduce potential hazards [29].

The ALARP (as low as reasonably practicable) principle is important in risk management. This concept divides risk into three categories: those risks that are unacceptable, those that are acceptable, and those in between where consideration needs to be given to the trade-offs between risks and the benefits (Fig. 2). Usually, a cost–benefit analysis may determine if a risk reducing effort is reasonable [27]. Acceptance criteria may be connected to the ALARP principle, which is not an acceptance criterion in itself, but mainly a way of thinking [29]. Acceptance criteria of sustainable fisheries may thus be related to the level of threats and hazards facing the fisheries that the stakeholders are willing to accept.

Acceptance criteria are often related to a specific quantitative upper or lower boundary, even though there may be large uncertainties attached to these estimates. For

sustainable fisheries, such boundaries may be defined by establishing:

- A global limit f_{θ}^* such that $f_{\theta}(\mathbf{I}_{\theta}(t)) \leq f_{\theta}^*$, as illustrated in Fig. 3.
- A limit $I_{j,\theta}^*$ such that $I_{j,\theta}(t) \leq I_{j,\theta}^*$ for all j , which means that the score on all performance indicators should be within the acceptable limits.
- A limit $I_{j,\theta}^*$ such that $I_{j,\theta}(t) \leq I_{j,\theta}^*$ for one or more specific j 's, which means the scores on one or a few specific performance indicators should be within the acceptable limits.

Qualitative interpretations are often easier to understand, but they may be more difficult to assess. Thus the best acceptance criteria may be both qualitative and quantitative [29].

The accident risk potential may, e.g., be measured as fatal accident rate (FAR), potential loss of life (PLL) or by using risk matrices. FAR and PLL are quantitative scales used, e.g., when assessing risk at petroleum installations. Risk matrix is a semi-quantitative method which evaluates different risk scenarios and potential outcomes in a systematic way [27].

An acceptance criterion for the number of employees may be established using the current level as a reference

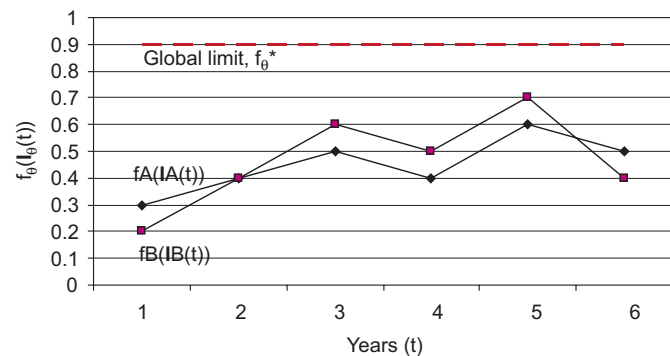


Fig. 3. A global tolerability limit and sustainability indices for system alternative 1 and 2.

Table 2
Norway's commitments to the Gothenburg protocol, and total emissions in 1990 and 2003, from [52,53], in 1000 ton

	Base year, 1990	Commitments to the Gothenburg protocol	Emissions 2003	Reduction within 2010 compared to 1990 (%)
SO ₂	53 000	22 000	22 800	58
NO _x	219 000	156 000	220 000	29
nmVOC ^a	300 000	195 000	301 400	35

^anmVOC is the abbreviation for non-methane volatile organic compounds.

level, if the management objective is to maintain the current level of employment. The quality of the fish delivered onshore may be measured in the paid prices per kg fish or income loss because of reduced quality.

An acceptance criterion related to a sustainable catch capacity level in the fishing fleet, may be difficult to define. The overcapacity in the fishing fleet is both environmentally and economically unsound. Methods of capacity assessment or measurement of utilization of capacity may be based on technical capacity characteristics and economic calculations [30]. For greenhouse gas emissions, commitments to international agreements and the government's environmental strategies may be used to establish criteria. An example is found in Table 2.

Table 2 shows that according to the Gothenburg protocol, Norway is committed to reduce the annual emissions of NO_x to a maximum level of 156 000 ton within 2010, a reduction of 45 000 ton compared to the predicted 200 000 ton [31]. The SO₂ emissions have already been heavily reduced since 1990, when the emissions were 58% higher than the commitments for 2010.

About 40% of the Norwegian emissions of NO_x are related to domestic shipping and fishery, and analyses show that the costs of reducing these emissions are moderate compared to efforts in other sectors. In order to comply with the commitments in the Gothenburg protocol, the Norwegian government aims at establishing new demands on emissions from new and existing ships and fishing vessels to reduce the eutrophication [1,32]. Such regulations may function as acceptance criteria. Establishment of acceptance criteria is a complicated task, because even though they may be based on scientists' recommendations, the political objectives and trade-offs are decisive for the result.

4. The performance of the fleets

In this section, the selected fishing fleets, A, B, C, D, and E are compared with respect to the sustainability attributes and performance indicators that have been identified.

4.1. Accident risk

Sintef Fisheries and Aquaculture has developed a risk picture of the Norwegian fishing vessels based on data from the Norwegian Maritime Directorate in the time period 1998–2003. The total number of accidents in all fisheries in this period was 1949, of which 61 fatal and 1888 personal injuries [25]. Table 3 shows the FAR value for the vessel groups discussed in this article.

The FAR value is the expected number of fatalities per 10⁸ h of exposure. In the statistics from the Norwegian Labour Inspection Authority the risk of occupational accidents for different industries are presented as number of deaths per 100 000 employees. If these work 1000 h a year, the number 10⁸ is obtained. In the fisheries, the number of man–labour years varies with different vessel

Table 3
Risk for the vessel groups, 1998–2003, own calculations based on statistics from [25,54]

Vessel type	FAR
A	152
B	35
C	13
D	12
E	19

Table 4
Risk of occupational fatalities in the fisheries and in other industries, average 2000–2004, own calculations based on statistics from [25,54,55]

Industry	Fatalities/100 000 employees
The fisheries (all fishing fleets)	79
Agriculture and forestry	16
Construction and building	4
Public administration	1
Transport and communication	5
Power and energy supply	5

groups from one year to another, as shown in Table 5. The FAR values presented in Table 3 are based on the numbers of man–labour years from 2003, as the statistics of the vessel groups from the Directorate of the Fisheries have been changed from 2002 to 2003, making comparison difficult. Thus some uncertainty is introduced, as the average man–labour years in the period 1998–2003 may be slightly different from the year 2003, which is used here. Another uncertainty factor is that the man–labour year numbers only include whole-year operated vessels, which may affect the smallest fishing vessels as many of them are only engaged part-time [25].

Table 3 shows that the FAR value is highest for vessel group A. The risk of occupational fatalities for the fishing fleets and other industries in Norway are presented in Table 4. Here the risk is measured in number of fatalities per 100 000 employees and not FAR, due to differences in the average man–labour years and exposure time. As can be seen, being a fisher is a dangerous occupation.

4.2. Employment

In Table 5, the number of employees and average man–labour years for 2004 are presented. In all, the smallest vessels employ more people than the largest vessels, but there are more man–labour years at the largest vessels.

Friends of the Earth Norway (In Norwegian: Naturvernforbundet) has estimated that by transferring the cod quotas from the factory trawlers to the conventional vessels with length, $10\text{ m} < \ell < 14.9\text{ m}$, the number of employees in the fisheries will increase by 500. However, the Norwegian

Table 5
Number of employees and average man–labour years, 2004, from [33]

Vessel type	No. of vessels	Total no. of employees	Av. man–labour years/vessel	Av. no. of working h/man–labour year
A	1111	1788	1.6	2020
B	231	903	3.8	2430
C	38	969	12.8	4480
D	15	782	27.6	3362
E	31	775	14.3	3889

Fishing Vessel Owners' Association (In Norwegian: Fiskebåtrederens forbund), contradicts this estimate because today the factory trawlers employ about 700 people. They mean that the calculations from the Friends of the Earth Norway are wrong, estimates showing that only 15–20 ton cod equivalents should be necessary to employ one person in the coastal fleet [6].

The average numbers of working hours per man–labour year reflect that the ocean fleet uses relief crew, while one man–labour year in the coastal fleet represents one employee [33].

4.3. Profitability

Profitability and added value are important objectives in the allocation process of the fish resources. In the fisheries, the scarcity factor is access to the fish resources, whereas the capital and labour are open to market prices. Trondsen and Vassdal [34] analyse the structure of the Norwegian fishing fleet in order to maximize added value per kg catch in the time period 1999–2003. They conclude that the smallest vessels have a higher added value per kg catch than the largest vessels, independent of type of fishery. The reasons are most likely that the smallest vessels have much lesser capital costs and operating costs, shorter operating time, and probably better utilize bycatch. Still, the added value per man–labour year is higher for the largest vessels. The reason may be that the government compensate lower added value per kg catch by allocating larger quotas to the large ocean vessels.

Table 6 shows average vessel profitability for the vessel groups in 2003 and 2004. The profit varies from one year to another, and the reasons may be varying external conditions, a weak quota foundation and overcapacity, increasing fuel prices, and unfavourable fish prices. A direct comparison between 2002 and the years earlier and 2003/2004 is difficult, due to vessel group changes in the statistics from the Directorate of the Fisheries.

Table 7 shows average vessel earning capacity per kg fish catch for the vessel groups in 2003 and 2004. The smallest conventional vessels have the highest score.

4.4. Quality

The Norwegian fisheries lose income due to raw material defects caused by the fishing gear or improper bleeding of

Table 6
Average vessel profitability NOK, 2003–2004 from [33,43]

Fleet	Operating profit		Profit before extraordinary items	
	2003	2004	2003	2004
A	18 599	42 822	−10 013	15 707
B	102 113	34 776	−25 697	−58 022
C	−133 509	686 414	−2 651 072	−1 113 347
D	−1 219 664	2 759 095	−4 609 452	527 724
E	−509 466	2 005 204	−3 330 964	258 751

Table 7
Average vessel earning capacity per kg fish catch, 2003–2004, own calculations based on statistics from [33]

Fleet	Earning capacity, NOK/kg fish catch	
	2003	2004
A	4.03	4.56
B	3.15	3.39
C	2.21	3.59
D	1.34	2.25
E	1.28	2.82

the fish onboard the fishing vessels. In 2003, about 8 million kg of fish were brought onshore with serious damage. The damage deteriorates the quality of the fish products. The fish-processing industry may reduce the price for the poor quality fish, and in 2003 this was done for 1.9 million kg cod [26].

The coastal fleet normally delivers fresher fish than the ocean fleet. The fishing gear has a great impact on the amount of damaged fish. Also, large catches impact the quality of the fish due to slower intake of the fishing gear, and thus increased standing time, increased pull-in forces which lead to increased pressure on the fish in the hauling equipment, more work, delays, etc. [35].

In the coastal fleet fishing for cod, the most common fishing gears are gillnet, longline, Danish seine and handline. In the ocean fleet, trawl is the most common fishing gear [36]. A study carried out by the Norwegian Institute of Fisheries Research shows that the highest frequency of quality defects caused by the fishing operation, was found on cod caught by net, and the lowest on cod caught by hand-line [37].

Calculations show that the fishing fleet alone may have lost more than NOK 300 millions from 1999 to 2002 because most of the cod was caught in a disadvantageous period of the year when the prices and the quality are low. Outside the coast of Finnmark the cod in general is of high quality, but during the Spring Fishery high quantities of cod are landed, the young cod, which seeks to the coast, is more exposed to deterioration due to capelin as the major feed [38].

The landed value for large cod (weight >2.5 kg) caught by the coastal fleet in Finnmark is in general lower than the average prices paid for large cod caught by trawlers. The reasons may be that the quality is better (e.g., than for cod caught by net), or that the grading from the trawlers are better suited the fish processing industry. For the smaller cod, the price differences are varying [38].

4.5. Catch capacity

The trawlers have much higher catch capacity than the smaller conventional vessels. In 2004, the average length of a factory trawler (D) was 61.4 m and the average age was 16 years. For the cod trawlers (E) the average length was 51 m and the average age was 18 years. For the conventional vessels (A) participating in the cod fisheries, the average length was about 11 m and the average age was 21 years. Gross tonnage weight differs from 13 in average of the smallest vessels to 740 in average for the factory trawlers [33]. The increased capacity development in the Norwegian fishing fleets has been thoroughly discussed by Standal [3,39]. In order to compare the different vessel groups with respect to technical capacity, it is necessary to extend the work of Standal.

4.6. Greenhouse gas emissions/acidification

There are huge differences in energy use between the fishing vessels. The distance to the fishing grounds, bad weather, wave height, low temperatures and icing, type of catching gears, and conservation of the catch are factors that impact the energy use [40]. The increasing oil prices reduce the profitability in the Norwegian fishing fleets, especially for those vessels with high fuel consumption, such as the shrimp trawlers [41].

There are no official statements of the exact energy consumption in the fishing fleet. In a project carried out by Sintef Fisheries and Aquaculture [40], the energy use from 1980 to 2002 was estimated for different vessel types. The calculations in this article are based on the same methods; by use of financial statements from the Directorate of the Fisheries [33,42,43], and information on fuel prices from Statoil, The Norwegian Petroleum Industry Association, Bunker Oil, and Norwegian Customs. By using fuel costs and fuel prices, and knowing the density of marine gas oil (MGO), the average fuel consumption for each vessel can be estimated.

The total consumption of fuel for the vessel groups were calculated by multiplying average use per vessel by the total number of year-round operated vessels in each group. In order to estimate the total emissions for the vessel groups, the fuel consumption was multiplied by emission coefficients (emission per kg combusted MGO). The emission coefficients represent an average for the fleet, introducing some uncertainty as the numbers are based on only a few engines. The coefficients can be found in Table 8.

The emission coefficient on NO_x varies from one engine type to another, and is also dependent on the engine's rotational speed and load. The SO₂ coefficient is more accurate, because The Norwegian Petroleum Industry Association every year publishes information on the average SO₂ level in MGO in Norway. The coefficient for CO₂ is only dependent on the carbon content in the fuel, and is thus representative for every vessel consuming MGO [40].

Table 9 shows the average fuel consumption per kg fish (round) for the vessel groups in this article. In Table 10, the total emission of greenhouse gases and the total fish catch for each vessel type can be found. The smallest vessels have the lowest fuel consumption. In this context, it is important to note that there are quite different external conditions between the vessel groups, which most likely favour the small vessels with shorter distance to the fishing grounds and limited operational season.

Table 8
Average emission coefficients for marine gas oil (MGO), middle high-speed engine, 80% load from [56], checked with [57]

Emission	Coefficient
NO _x	0.064
CO ₂	3.17
SO ₂	0.0034
CO	0.002
PM ^a	0.0008
HC ^b	0.002

^aPM: particles formed by incomplete combustion of fuel.

^bHC: hydro carbons.

Table 9
Average fuel consumption kg/kg fish for the vessel groups, 2003 and 2004, own calculations based on methods and statistics from [40]

Fleet	Fuel kg/kg fish	
	2003	2004
A	0.17	0.15
B	0.18	0.15
C	0.38	0.32
D	0.57	0.47
E	0.57	0.54

Table 10
Average emissions and total catch for the vessel groups, 2004, in ton [40]

Fleet	CO ₂	NO _x	SO ₂	CO	PM	HC	Total catch
A	48 486	979	52	31	12	31	98 348
B	37 759	762	40	24	10	24	77 566
C	67 838	1370	73	43	17	43	68 203
D	111 404	2249	119	70	28	70	74 858
E	165 995	3351	178	105	42	105	96 776

5. Cost–benefit analysis

The previous discussion shows significant differences in vessel group performances. Related to the systems engineering process, the discussion may be part of the specification of system performances. The attributes of sustainability create a starting point for definition of performance requirements to the system or the vessel groups. An evaluation of system performances should be a valuable contribution for making decisions, e.g., which efforts should be implemented where, in order to increase sustainability. Still, there is the challenge of preferences: Are economic aspects more important than emission of greenhouse gases? Should quality of the fish meat be higher ranked than safety of the fishers? To solve such issues, multi-criteria decision-making methods may be applicable. There are several methods available, see, e.g., [44,45].

The challenge of weighting the preferences may lead to further controversial issues, such as measuring the costs of implementing new efforts to increase sustainability to their benefits; a cost–benefit analysis, which is further discussed here. Cost–benefit analysis is a systematic approach used to evaluate advantages and disadvantages of different solution alternatives. Such analyses are often part of a strategic planning within companies or in the society. Cost–benefit analysis facilitates ranking of different alternatives, and classical cost–benefit analysis measures advantages and disadvantages financially. A common criticism is that the focus of the analysis mainly is on the economic transformation calculations, and not on the human, environmental, corporate, and societal aspects involved [46].

Energy use and emission of NO_x in the fishing fleet are emphasized by the Norwegian government's efforts to comply with the Gothenburg protocol. Recently, The Norwegian Pollution Authority published a report analysing the costs and benefits of different technological solutions that may reduce the NO_x emissions from ships and fishing vessels [31]. Another problem of the fishing fleets is the risk level, which is very high compared to other industries. In the following, the attributes of greenhouse gas emissions and safety are compared for the vessel groups.

The costs shown in Table 11 are based on accident costs calculated by the Norwegian Centre for Transport Research [47,48], and the emission costs are based on a study carried out by Western Norway Research Institute

Table 11
Costs of fatalities and greenhouse gas emissions, NOK

Costs	NOK
Costs per fatality	21 500 000.00
Costs NOK/kg CO ₂	0.35
Costs NOK/kg NO _x	70.00
Costs NOK/kg SO ₂	60.00
Costs NOK/kg CO	0.10
Costs NOK/kg PM	60.00
Costs NOK/kg nmVOC	35.00
Costs NOK/kg CH ₄ ^a	0.90

^aCH₄ is methane.

Table 12
Costs of fatalities and greenhouse gas emissions for the fishing fleets, 1998–2003, based on [43,47,49], 1000 NOK

Vessel group	Costs, fatalities	Costs, emissions	Total costs	Costs NOK/kg fish
A	752 500	567 767	1 320 267	2.32
B	107 500	534 013	641 513	1.30
C	43 000	919 424	962 424	2.36
D	21 500	1 529 853	1 551 353	3.39
E	43 000	1 787 134	1 820 134	3.46

for the Norwegian Railway Company (NSB) [49]. Table 12 shows the total costs of greenhouse gas emissions and occupational fatalities estimated for the fleets in the time period, 1998–2003.

The calculations in Table 12 show that the emission and fatalities costs are higher for the trawlers than for the conventional vessels. The emission costs are quite high for the large vessels, whereas the small coastal vessels have very high costs due to the high number of fatalities. Change of energy carrier for the largest vessels, such as use of natural gas (LNG) instead of MGO, may reduce the greenhouse gas emissions and the acidification [40] to such an extent that the accident costs for the smallest vessels may exceed the emission costs for the largest vessels. Vessel group B has the lowest costs NOK/kg fish. The reason is that even though the costs of greenhouse gas emissions are almost equal for vessel group A and B, the number of fatalities is much higher for vessel group A. The costs of the fatalities show the importance of improving safety in the fishing fleets.

There is uncertainty connected to the estimates in Tables 11 and 12. Estimating greenhouse gas costs and accident costs are subject to uncertainty in the methods used, data collection, and to definition of the system boundaries [49]. Besides, there is uncertainty related to the estimates of greenhouse gas emissions, as the energy consumption in the fisheries is estimated indirectly from the average fuel costs of each vessel. Due to the changes in the statistics from the Directorate of the Fisheries, the emissions and the total catch in the period 1998–2003 are

aggregated numbers from 2003, whereas the number of accidents are based on observations in the whole period.

The accident costs would increase if the costs of injuries were to be calculated and added to the costs of fatalities. The trawlers have a higher number of reported occupational injuries than the small conventional vessels [25]. Due to high uncertainty in the reported numbers of injuries, and also uncertainty in cost estimates of injuries, these calculations are not carried out. Assuming that there are more injuries at the large vessels, the costs per kg fish would increase for those vessels.

Despite the uncertainty connected to the estimates, the importance of increasing the sustainability in the fishing fleets is clearly demonstrated. The estimates also show that including accident risk or safety into the concept sustainable fisheries, may give a more ambiguous picture of the sustainability performance of the vessel groups.

6. Discussion

This article has identified six important attributes of sustainability in the Norwegian cod-fishing fleet: accident risk, employment, profitability, quality, catch capacity, and greenhouse gas emissions/acidification. The vessel groups are evaluated, accordingly, and possible acceptance criteria are suggested, even though they are not fully investigated. The system boundaries have been limited to the fishing fleets in the operational phase, leaving the natural marine system outside the analysis. Based on the previous discussions, the following conclusions can be drawn:

- *Accident risk*: The fatal accident rate is very high for the smallest vessels. There is a higher rate of occupational injuries at the largest vessels. The overall risk for the fishing fleet is very high compared to other industries.
- *Employment*: The smallest vessels employ more people in all, even though the largest vessels have more employees per vessel.
- *Profitability*: The smallest vessels have the highest earning capacity.
- *Quality*: The quality of the fish meat is influenced by many factors, such as the catching gear. Investigations show that the fish caught by net gives the lowest quality, whereas the fish caught by hand-line gives the best quality. In general, it seems as the trawlers attain higher average prices for the fish than the small conventional vessels.
- *Catch capacity*: The catch capacity is obviously highest for the largest vessels. Presently, it is difficult to estimate which vessel group has the highest degree of over-capacity.
- *Greenhouse gas emissions/acidification*: The largest vessels, using active fishing gear, have the highest fuel consumption per kg fish.

The debate about sustainability in the fishing fleets, e.g. [6,14,50], seems to leave out the attribute accident risk.

Statistics show that there is a much higher risk of fishers dying in accidents related to small vessels than large vessels. By including the costs of serious accidents, the sustainability in the fishing fleets may turn out more ambiguous. Even though there is some uncertainty related to the calculations of the costs; still, if the largest vessels use LNG instead of marine gas oil, the greenhouse gas emissions may be reduced to such an extent that the costs of fatal accidents for the small vessels may exceed the costs of the emissions for the largest vessels. The calculations also show the importance of reducing the number of accidents in the fisheries.

The basis of calculations and data does not emphasize differences in external conditions that affect the energy use between the vessel groups. It is assumed that this is a disadvantage to the trawlers, being subject to stricter regulations in admission to the fisheries through geographical areas and time limits.

If the fishing fleets are to become more sustainable, fisheries management should be able to evaluate the effectiveness of its objectives. Use of performance indicators and acceptance criteria may facilitate such evaluations. In systems engineering, the process of identifying performance indicators is based on determining the requirements to the system; in this case a sustainable fishing fleet. The Norwegian fisheries management aims at reducing overcapacity by introducing structural changes. The effects of such efforts, should be monitored in order to evaluate their consequences related to management objectives. Effective implementation presupposes that the efforts increase sustainability in the fishing fleets.

Presently, there is a lot of information available about the Norwegian fisheries. However, the data may not easily be used to evaluate the performance of fisheries management related to goal achievement over time. Thus, the discussion in this article has visualized and assessed some important attributes of sustainability in the cod-fishing fleets, and proposed performance indicators that should be used to evaluate the fishing fleet on a regular basis. Such evaluations may contribute to improved sustainability in the fisheries and a better decision basis for fisheries management in the future.

7. Further work

- Acceptance criteria for the performance of the fishing fleet with respect to sustainability should be further investigated in order to make concrete recommendations to the fisheries management.
- Use of performance indicators in the decision-making regarding the fishing fleets, presupposes a ranking of the attributes. Such a ranking would enable calculation of a sustainability index as an aggregate of the scores on the performance indicators. Ranking of the attributes may be part of the iterative phase of analysis and optimization of system alternatives in the systems engineering process. Such a ranking is under investigation.
- In this article the system boundaries, and thus the comparison of sustainability, has been limited to the cod-fishing fleet in its operational phase. Evaluation of other parts of the value chain, e.g., the fish processing industry, would produce performance indicators based on different system requirements to the vessel groups, such as continuous delivery of fish. In such a perspective, the sustainability performance of the vessel groups may turn out somewhat different from this evaluation.
- The interaction between fisheries' regulations, quota allocations, and sustainability in the fisheries is not finally clarified by the discussion in this article, and should be further explored.

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Article 3

Are the smallest vessels the most sustainable? Trade-off analysis of sustainability attributes

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Are the smallest fishing vessels the most sustainable? -Trade-off analysis of sustainability attributes

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Abstract

This article discusses application of systems engineering principles and trade-off analysis of sustainability in the fishing fleet. Sustainability in the fishing fleet may be characterized by seven attributes, measured by performance indicators. Evaluations show that the energy consumption is higher for the Norwegian ocean going fleet than the coastal fleet, whereas the opposite is the case for the number of fatalities. An important part of the systems engineering process is analysis and optimization of system alternatives. Thus, the main objective of the article is to investigate ranking of the sustainability attributes, which implies use of multi-attribute decision-making methods. The Analytic Hierarchy Process was used to interview stakeholders to the fishing fleet about their preferences. The article concludes that if “accident risk” is weighted as the most important attribute, the smallest fishing vessels are not as sustainable as often claimed.

Key words: Sustainability, Fishing fleet, Analytic Hierarchy Process

1 Introduction

Sustainable resource management is an important objective in most fisheries [1]. Overcapacity in the fishing fleet is one of the major threats to sustainability, because it leads to more effective fishing vessels and gear, which again increase the pressure on quota limits [2, 3]. The main disciplines involved in fisheries management are bio-economics and social sciences. Still, overcapacity is also a technological problem, which implies a stronger integration of technological aspects into fisheries management [4]. Systems engineering has been introduced as a feasible process for handling sustainability issues in the fisheries [5, 6].

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The concept of sustainability is vague, and various interpretations appear in discussions about which fishing vessels are the most sustainable [7]. With respect to reductions of overcapacity in the fishing fleet, the system alternatives, which in this case are the different vessel groups, may give advantages and disadvantages. Fisheries management decisions impact a range of stakeholders with interests in the fisheries, and conflicting situations may occur, especially when considering complex issues like sustainability: One type of fishing technology may give higher income, but fewer employees. Another solution may improve safety, but also increase emissions of CO₂. In the systems engineering process, examining alternative solutions and finding the best one, implies trade-off analysis carried out in an iterative loop until the best solution is found [5].

Trade-off analysis of sustainability in the Norwegian cod-fishing fleet is discussed in this article, as a further elaboration of systems engineering principles related to the fisheries [5]. The trade-off analysis is based on the results from a performance evaluation of the vessel groups in the cod-fisheries [6]. Multi-criteria decision analysis is evaluated on the basis of usefulness for assessing attributes of sustainability, and the Analytic Hierarchy Process (AHP) is used to visualize the consequences of trade-off decisions, and to show the importance of stakeholder inclusion in the decision-making process. The article also discusses how sustainability in the fishing fleet may be measured and evaluated on a regular basis, by using an index of sustainability. The system boundary is limited to the fishing vessels in the operational phase, representing the technological system interacting with the natural marine ecosystem.

1.1 Attributes of sustainability in the Norwegian cod-fishing fleet

Sustainable development may be characterized by three dimensions; the ecological, social, and economic dimension. In order to find out more about sustainability in the fishing fleet, the performance of the Norwegian cod-fishing fleet was evaluated at six attributes; accident risk, employment, profitability, quality of the fish meat, and greenhouse gas (GHG) emissions/acidification [6], shown in Figure 1. The selection of the attributes used to assess the various vessel groups is very important, because some attributes may favor one vessel group at the expense of others. The attributes were selected based on government objectives of sustainable resource management, found in Table 1.

From the system boundaries, it may be questioned if bycatch/selection is a relevant attribute since it mainly impacts on the natural marine ecosystem. Nevertheless, bycatch may affect profitability of the fishing vessel, and selection may impact fuel consumption. Bycatch/selection has also been considered in other environmental analyses of fisheries [8].

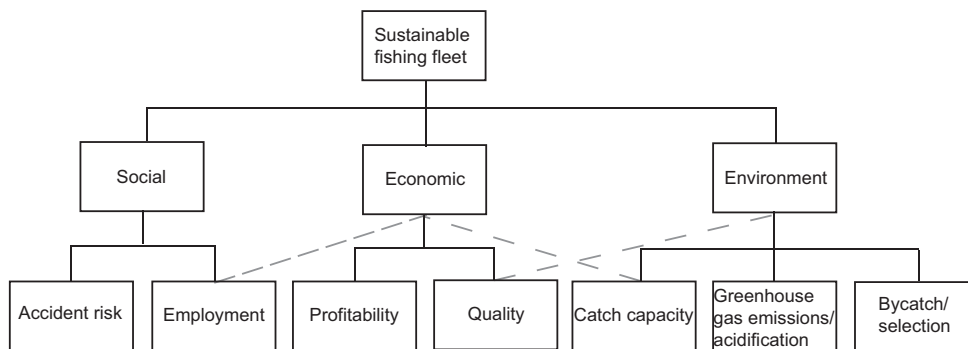


Fig. 1. Sustainability attributes of the cod-fishing fleets.

Table 1

The attributes related to objectives of sustainable fisheries management, [6, 9, 10].

Attributes	Objectives
Accident risk	Reduce accident risk
Employment	Maintain rural settlement
Profitability	Increase profitability
Quality	Increase quality of fish meat/reduce damage
Catch capacity	Reduce overcapacity in the fishing fleet
GHG emissions/acidification ^a	Reduce emissions
Bycatch/selection	Reduce bycatch/improve selection

^a This attribute is related to emissions of CO₂ and NO_x.

The main results from the system evaluation are summarized in Table 2. The attributes have been evaluated by using performance indicators. The attribute “accident risk” is measured by the fatal accident rate (FAR), and “employment” is measured by “average man-labour years per vessel”. “Profitability” is measured by “earning capacity, NOK/kg fish”, and “quality” is assessed by damage to the fish meat by the catching gear, and prices paid per kg fish. “Catch capacity” is measured by technical parameters, such as length and gross tonnage weight in the statistics from the Directorate of the Fisheries [11–13], and “GHG emissions/acidification” is measured by the indicator “kg fuel/kg fish”.

Vessel groups A-E are in accordance with the cod-fishing vessel groups in the statistics from the Norwegian Directorate of the Fisheries from 2003 and onwards [11–13], according to length (ℓ) and type:

A: Small coastal vessels (net, hand line, Danish seine, long-lining), $\ell < 15\text{m}$

Table 2

The results from the system evaluation of the vessel groups in the Norwegian cod-fisheries [6].

Attributes & performance indicators	A	B	C	D	E
Accident risk, 1998-2003, FAR ^b	152	35	13	12	19
Employment, 2004,					
Average man-labour years/vessel	1,6	3,8	12,8	27,6	14,3
Profitability, 2004,					
Earning capacity, NOK/kg fish	4,56	3,39	3,59	2,25	2,82
Quality, 1-5 (5 is best)	5	3	5	3	3
Catch capacity, 2004, 1-5 (5 is best)	1	2	3	5	4
GHG emissions/ acidification,					
2004, kg fuel/kg fish	0,15	0,15	0,32	0,47	0,54

^b Fatal Accident Rate (FAR) is the mean number of fatalities per 10⁸ hours of exposure.

B: Medium coastal vessels (except trawlers), $\ell = 15 - 27,9\text{m}$

C: Large conventional vessels (long-lining), $\ell > 28\text{m}$

D: Factory trawlers, possibly combined with shrimp trawling

E: Cod trawlers, possibly combined with shrimp trawling

The smallest vessels, groups A and B, have the highest FAR, the lowest average employment per vessel, the highest earning capacity, the lowest catch capacity, and the lowest fuel consumption. Quality of the fish meat is assessed by asking stakeholders. The attributes quality and catch capacity are ranked according to their degree of goal-achievement, with an equal distance between the scores. This means that in Table 2, the score 5 does not indicate a “5 times lower catch capacity” [6].

The quality of the fish meat and the amount of bycatch depend on the use of gear. In vessel group A, for instance, the vessels use several types of gear, also in combination. The issue of quality is complex, and in recent years, frozen fish has achieved the highest prices [14]. Even though there are attempts of improving the quality of the fish caught in the Norwegian fisheries, e.g., the “Røst-project” [15, 16], the quality problem should be further investigated. For bycatch/selection, the attribute which has been added in this article and thus is not shown in Table 2, long-lining and trawl are usually the most affected gears in the cod-fishing fleet [8].

The way the information is presented in Table 2 makes it difficult to assess which

of the vessel groups are more sustainable than the others, because the performance indicators are measured in different units. It is also difficult to assess whether the overall level of sustainability of the fishing fleets is increasing or decreasing. Thus, a systematic approach to decision-making and trade-off analysis is discussed in the next section.

2 Systems engineering and multi-criteria decision-making

Systems engineering has been introduced as an interdisciplinary, systematic, and holistic approach to problem solving in fisheries management, rooted in the traditions of the engineering disciplines [5, 6]. Systems engineering deals with analysis and design, operation, and maintenance of large integrated systems in a total life cycle perspective. Technology, management, legal aspects, environmental and social issues, finances, and corporate strategies are taken care of by a total system integration. The literature on systems engineering related to fisheries is scarce, but two systems engineering projects were carried out in the U.S. east coastal fisheries in the 1970's. Hamlin [17] argues that the fishing industry can benefit from use of systems engineering, and that systems engineering can be used at all levels of application, from evaluating a simple change in fishing procedure to managing and guiding the industry on a global scale.

The heart of systems engineering is the systems engineering process, which expands on the common sense strategy of understanding a problem before solving it, examining alternative solutions, and verifying that the chosen solution is correct before implementing it. The basic steps of the systems engineering process are, 1) identification of needs and stakeholders to the system, 2) definition of system performance requirements, 3) specification of system performances, 4) analysis and optimization of the system alternatives, 5) designing and solving, and 6) verification and testing of the system. Use of the systems engineering process in fisheries management may give increased visibility and a reduction of the risks associated with the decision-making process [5].

An important part of systems engineering is analysis and optimization, which implies a decision situation. The connection between the systems engineering process and decision analysis is shown in Figure 2.

2.1 Multi-attribute decision-making to evaluate fishing vessel impact on sustainability

Multi-criteria decision-making (MCDM) has attained interest in several management fields, including the fisheries. Several stakeholders with conflicting objectives

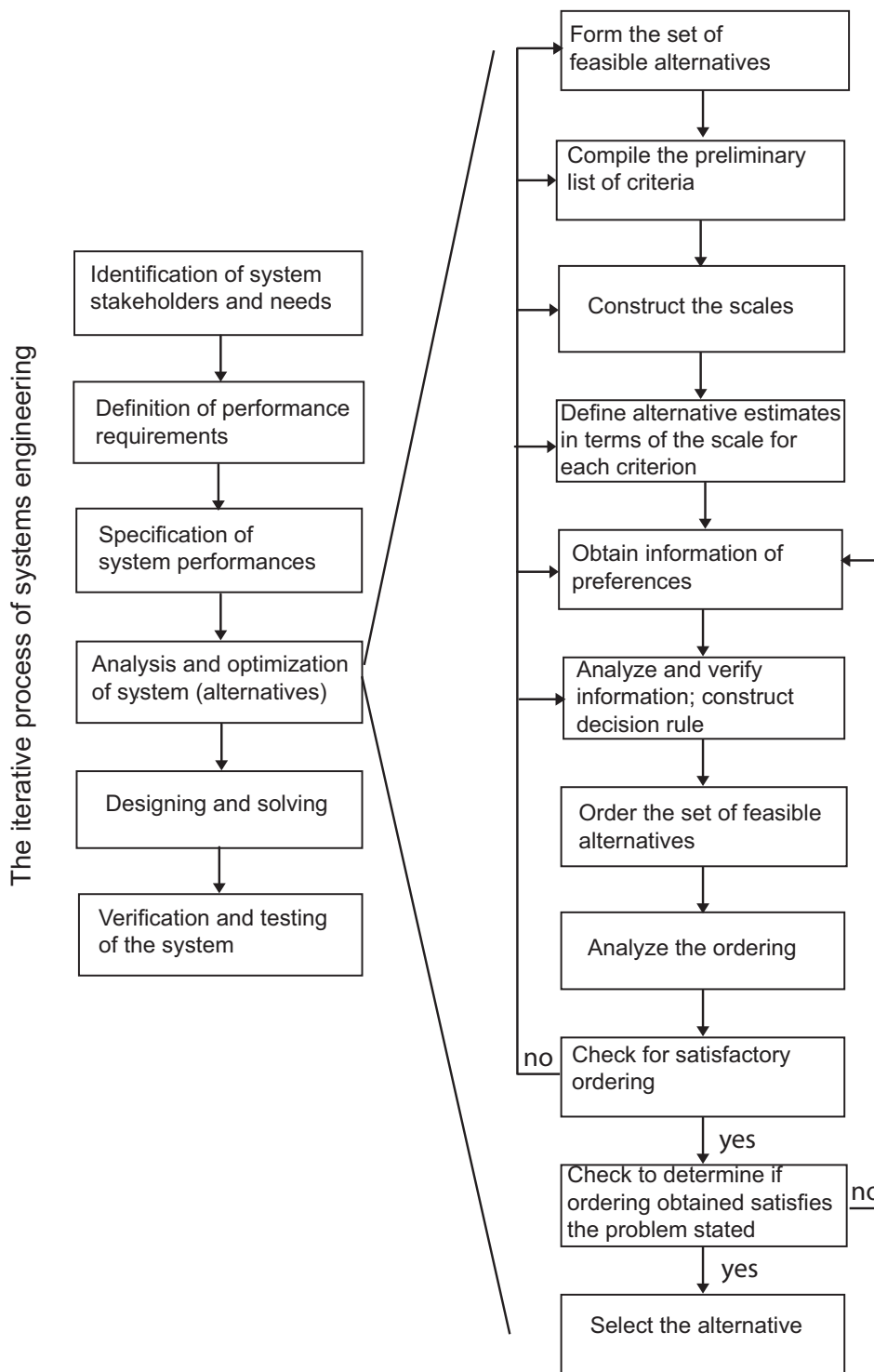


Fig. 2. The systems engineering process and multi-criteria decision-making, based on [5, 18].

and needs are involved in the fisheries. A management model that incorporates multiple objectives in the decision process seems appropriate [19]. MCDM methods may enable the necessary trade-offs to become more visible.

MCDM methods may be subdivided into multi-objective decision-making (MODM) methods and multi-attribute decision-making (MADM) methods. MODM methods are used to identify a preferred alternative among a potentially infinite set of alternatives. Options are defined implicitly by a set of constraints, and most of the MODM approaches are based on mathematical programming [20]. An example may be found in [21], where a multi-objective programming model is used to investigate trade-offs between regional income, regional employment, and economic rent of the Norwegian cod fisheries in the Barents Sea in elucidation of the sharing of the total allowable catch between large and small fishing vessels.

MADM methods are for preference decisions, such as evaluation, prioritization, and selection, over the available alternatives. The alternatives are characterized by multiple, and usually conflicting, attributes. The MADM methods are designed for choosing between specific alternatives, whereas the MODM methods usually have a rather complicated mathematical form that need computer support [20]. In fisheries management, it may be difficult to involve stakeholders in the decision-making by use of the MODM methods, since the theory behind is complicated. MADM methods are easier to understand and apply. Evaluation of sustainability in the fishing fleet is about choosing among different design options, and MADM methods could be useful.

There are numerous MADM methods available, ranging from relatively simple and straightforward models to advanced mathematical approaches. Multi-criteria problems are often complex and conflicting, reflecting different viewpoints and often changing with time. One of the advantages with MADM methods is that the necessary trade-offs become visible. There is not a right answer to the problem, but MADM methods help structure and organize the decision problem to guide the decision-makers [20].

2.2 *Multiple attributes and the basic decision problem*

In this article the attributes (Figure 1), ranging over economic, environmental, social, and technological topics, have conflicting objectives. The action options are the system alternatives, A, B, C, D, E , and their sustainability performance can be assessed at five attributes of concern, X_1, X_2, \dots, X_5 by use of performance indicators. Some aspects of the typical decision problem are [22, 23]:

- To identify alternatives that may be few and explicit, or infinitely many and implicit, e.g., best allocation of available resources across competing needs.
- To generate relevant criteria or attributes of the alternatives. Criteria is an initial

Table 3

Ranking of the results from the system evaluation of the vessel groups in the Norwegian cod-fisheries, [6], 1-5, 5 is first rank. The attributes quality of the fish meat and bycatch/selection have been left out due to lack of quantitative data. The attributes are arbitrary weighted and summed. The best alternative have the highest score.

Attributes		Weights, %	A	B	C	D	E
X_1	Accident risk, 1998-2003	$w_1 = 40$	1	2	4	5	3
X_2	Employment, 2004 ^c	$w_2 = 10$	1	2	3	5	4
X_3	Profitability, 2004	$w_3 = 20$	5	3	4	1	2
X_4	Catch capacity	$w_4 = 15$	1	2	3	5	4
X_5	GHG emissions/ acidification, 2004	$w_5 = 15$	5	4	3	2	1
$\sum w_i X_i$			2,4	2,5	3,6	3,75	2,75

^c This attribute is ranked for an individual vessel. Comparing the vessel groups, the smallest vessels employ more people in total.

candidate set of key factors, whereas attributes are quantitative measures of performance associated with a criterion. In this article, the attributes are measured by performance indicators.

- The incommensurable units; the units of one attribute may be NOK or Euro, and those of another may be human lives lost.
- Time; consequences appear over time, such as monetary flows over time.
- Uncertainties; due to uncertain quantities.

2.3 Ranking of the sustainability attributes

Table 3 ranks the system alternatives, i.e., vessel groups for each attribute. A simple ranking of the vessel groups assumes that all attributes are equally important. The ranks or scores give no indication of the differences between the vessel groups for the attributes. Table 4 shows that alternative D has the most 1. places, but is the worst and second worst option in two attributes. In some cases these attributes may be more important to emphasize. If the attributes are not equally important, weights can be used. In Table 3, alternative D is the most sustainable when the attributes are ranked, weighted, and summed. The weights in the table are just an example, because stakeholders will weight the attributes differently. The system boundaries may also favour the largest vessel groups when considering employment per vessel. For example, alternative D has the highest number of employees due to processing, but onboard processing may replace employees working in the processing industry

Table 4

The simple rank method, [20]. The option with the highest number of first places is selected.

Alternatives	1. places	2. places	3. places	4. places	5. places
A	2	0	0	0	3
B	0	1	1	3	0
C	0	2	3	0	0
D	3	0	0	1	1
E	0	2	1	1	1

onshore (outside the system boundaries). In the table, the smallest vessels have the lowest employment, but in total vessel group A employ more people than any other vessel group.

Another MADM method is the ordinal method which is similar to the simple rank method, except that the attributes are weighted. The weights express the importance of each attribute relative to the other attributes. There are numerous weight assessment techniques [20].

A MADM method, called the Analytic Hierachy Process (AHP), was used in the evaluation of preferences among stakeholders to the Norwegian fishing fleet, in order to determine weights to the attributes. Trade-off analysis helps decision-makers to analyze the set of efficient alternatives, which means deciding which of the system alternatives is preferred, and how much the differences in the scores of the attributes matters to the decision-maker [24].

2.4 *The Analytic Hierarchy Process*

The AHP was developed by Saaty more than 25 years ago [25]. The AHP provides a framework for analysis of the preferences of stakeholders within the fisheries system, and may enable the managers to justify decisions based on the priorities expressed by stakeholders explicitly [26]. An AHP hierarchy has at least three levels: The top level, which is the overall goal of the problem, the middle level, which consists of multiple attributes that characterize the alternatives, and the bottom level, which shows the competing alternatives [20]. The problem hierarchy for the Norwegian cod fishing fleet is shown in Figure 3.

In AHP, the elements of a problem are compared in pairs with respect to their relative impact on a common property. The elements are compared at a single level with respect to an objective from the higher level, and this process is repeated up

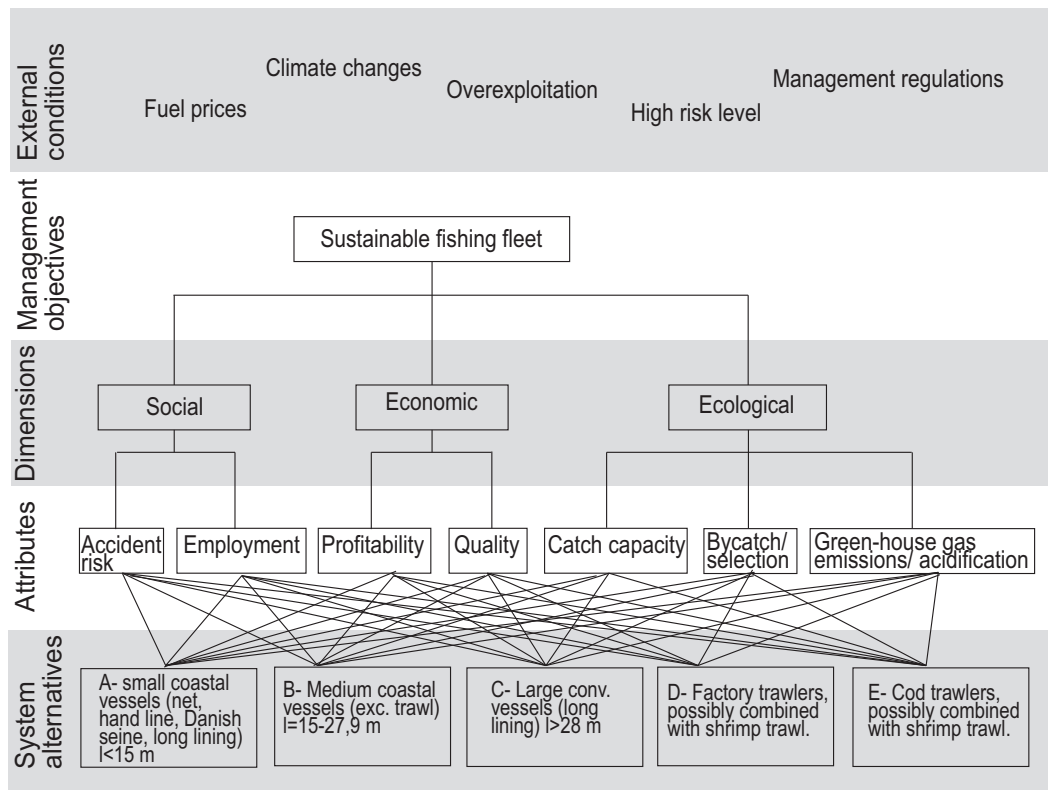


Fig. 3. Sustainability attributes of the cod-fishing fleets.

Table 5
The fundamental scale for pairwise comparisons, [25].

Numerical values	Description
1	Equally important or preferred.
3	Slightly more important or preferred.
5	Strongly more important or preferred.
7	Very strongly more important or preferred.
9	Extremely more important or preferred.
2,4,6,8	Intermediate values to reflect compromise.

the hierarchy. Saaty [25] created a nine-point scale to simplify the comparisons, and the numbers express the preference between the two elements, shown in Table 5. Inconsistency in the pairwise comparisons is evaluated by using the eigenvector prioritization method. The consistency ratio should be about or less than 10% to be acceptable [25].

In the Yoron Island, Japan, fishery stakeholders were involved to consider the im-

portance of different fishery sustainability indicators [27]. In Denmark, the AHP was applied to evaluate the preferences of the various stakeholders for management of the haddock and whiting fisheries [28]. When a group participates in making a decision, it is a question of how the judgments should be used in the process, and how they should be combined. Different rules may be used, and Saaty[25] suggest calculating the geometric mean of the preferences. Decisions may also change over time, and judgments may be changed. The method of AHP has been thoroughly debated, e.g., [29–37].

3 Stakeholders' preferences of sustainability attributes in the fishing fleet

Almost every important decision influences several stakeholders. The interested parties may formulate the problem at hand differently, they may differ in assessments of uncertainties, in evaluations of outcomes on attributes, and in trade-offs among attributes [38]. In [5], several stakeholders to the fisheries were identified, for example the fishers and shipowners, the bureaucrats, the fish processing industry, sector organizations, and so on. These stakeholders have different needs, depending on their relationship to the fisheries. One would expect the fishers and the ship owners to be most concerned with profitability, because the main need for a job is motivated by earning money to provide for themselves and their families. The bureaucrats may have different attitudes as they represent the instruments and the policies of the Norwegian fisheries management. Profitability is important to them, but they may emphasize employment and pollution as well. The local communities would probably also be concerned about accident risk, as a loss of a citizen in a small rural community causes a lot of stress and grief. The fish processors would obviously be preoccupied by the amount and quality of the fish delivered, as well as the regularity. The society in general, the sector organizations, and scientists may be concerned about the ethics of fisheries [39].

In order to make a decision, for example about the structure and composition of a sustainable fishing fleet, the attributes have to be weighted according to importance and relevance. Such weighting may be carried out by use of AHP, and is a matter of visualizing preferences, which in most cases regarding the fisheries, appear from political prioritization. Obviously, the stakeholders would weight the attributes differently. In AHP, the attributes are compared pairwise, by use of a scale as presented in Table 5. Still, it is difficult for stakeholders to assess the sustainability attributes according to such a scale, because the concept “sustainable fishing fleet” may be interpreted differently, as well as the lack of total independence between the attributes, for example, between fuel consumption and profitability.

The AHP method was used in interviews and questionnaires of nine stakeholders to the Norwegian cod-fishing fleet. The stakeholders were selected based on the stakeholder analysis in [5]. The number of stakeholders is low, because many

Table 6

The stakeholders involved in the weighting process by use of AHP.

Stakeholder	Number of persons
Fishers/shipowners	2
The Norwegian Fishermen Association	2
Fisheries scientists	2
The Ministry of Fisheries and Coastal affairs	2
Norwegian Society for the Conservation of Nature	1

stakeholders did not want to participate when they heard about the topic of the interview. Especially, it was difficult to discuss sustainability with fishers, because use of multi-criteria decision analysis was something many of them had not heard of and sustainability something that did not really bother them. Nevertheless, the main objective of the interviews was not to find a representative weighting of the attributes for the stakeholders involved in the fishing fleet, but to determine whether use of AHP would be feasible in fisheries management contexts. The stakeholders were asked to assess the attributes, in addition to the quantitative results from [6] that were used directly in the model. The objective of the interviews was to evaluate and visualize the usefulness of AHP with respect to decision-making regarding a sustainable fishing fleet, and to discuss the various preferences among different stakeholders. Table 6 shows the stakeholders involved. The chosen stakeholders represent various, and sometimes conflicting interests, and they did weight the attributes differently. Table 7 shows the most important attributes to the stakeholders. All stakeholders weighted the attribute safety as most important, except The Norwegian Society for the Conservation of Nature, who weighted bycatch/selection and GHG emissions/ acidification the highest.

The results from the preference analysis by AHP are based on too few individuals to be representative for the Norwegian fishing fleet. There are also some problems related to the results: The first obstacle to the preference evaluation is the ambiguity of the main objective of the decision problem: Achievement of a sustainable fishing fleet. Thus, the stakeholders were given a short explanation of the meaning of a sustainable fishing fleet, where the emphasis was put on increased sustainability in future technological development. Then the decision-makers had to determine the relative importance of “profitability” to “employment”, “safety” to “emissions of GHG and acidification”, and so on, according to Table 5. The difficulty in the weighting process was also increased slightly due to some possible dependencies between the attributes, for example, between profitability and emissions of GHG (the latter may be related to the vessel’s fuel consumption). The main problem was, however, that those interviewed lost overview of the consistency between their

Table 7
Stakeholders and the most preferred attribute.

Stakeholder	Attribute
Fishers/shipowners	Accident risk
The Norwegian Fishermen Association	Accident risk
Fisheries scientists	Accident risk, Bycatch/selection
The Ministry of Fisheries and Coastal affairs	Accident risk
Norwegian Society for the Conservation of Nature	Bycatch/selection, GHG emissions/ acidification

comparisons. The author used a computer program called Criterium Decision Plus [40], which calculates the consistency index of the ratings. Still, it was not very easy to reduce the inconsistencies in an interview situation, and in a few cases the consistency ratio ended up somewhat above the recommended level of 10%. Two of the stakeholders involved were asked to weight the attributes by use of a questionnaire. These two had among the best consistency ratios of the stakeholders.

Despite the obstacles, the process of using AHP to evaluate stakeholder preferences, was positive. The AHP structured the decision-problem, and it facilitated stakeholder involvement, which is important in fisheries management. The preference evaluation process also gave the stakeholders the opportunity to discuss sustainability topics and reflect on their own opinions.

The AHP visualizes the weighting process and the trade-offs explicitly, and it structures the decision-making situation. Evaluating sustainability in the fishing fleet is difficult, especially because the different fleets do not have the same framework conditions. Still, the results from this evaluation shows that the selection of attributes is very important. If the concept of “sustainability” is just related to fuel consumption and biological impact, such as bycatch and selection, the smallest vessels may seem the most sustainable. However, most stakeholders weighted “accident risk” the highest. This means that even though the smallest vessels have the lowest fuel consumption, highest profitability, best quality, and bycatch/selection, the results of AHP most often showed that the smallest vessels were slightly less sustainable than the largest vessels, due to the weights put on the attribute safety, of which the largest vessels have the much better score.

Table 8

An index for vessel group A in the Norwegian cod-fisheries, () indicates goal fulfillment.

Performance indicator	2003	2004	Change (%)
FAR	152.0	150.0	-1.47%(+)
Average number of man-labor years	1.7	1.6	-2.94%(-)
Earning capacity	4.03	4.56	13.26%(+)
Catch capacity, average length (m)	11.12	11.24	1.12%(-)
Fuel consumption	0.17	0.15	-9.18%(+)
Index, A	.	.	19.86%

4 A sustainability index for measuring the situation in the Norwegian fishing fleet

An index may be a simple and clear way to present evaluations of fisheries management policies. If a performance index for the Norwegian fishing fleet is to be obtained, some kind of weighting of the performance indicators has to be carried out. Use of the AHP method may be one way to do that.

An index is a simplification of the information measured by performance indicators [6]. There are challenges connected to use of an index, as the weighting and normalization of the indicators introduce a range of uncertainty to the total index, depending on the amount of aggregation. Selection and weighting of performance indicators require trade-off decisions regarding which attributes of sustainability are more important than others [5].

Standal [4] presents the changes (%) in technical capacity for the shrimp trawlers between 40 and 60 metres of length in the time period from 1973 to 2000. Similar changes, that may be considered to be normalization of data, can be presented for other attributes, presented in Table 8 and Table 9, based on [6], [11], [12], [41]. The attributes quality and bycatch/selection have been left out due to lack of reliable data.

The indices calculated in Table 8 and Table 9, are found by summing up the changes in the performance indicators. Indices may be calculated for the other vessel groups as well. As previously discussed, the indicators are based on attributes that are related to management objectives. If fisheries management does not consider the objectives to be equally important, they may put weights to them. Most of the stakeholders interviewed weighted the attribute "accident risk" as the most important, which may indicate that the performance indicators should not be considered

Table 9

An index for vessel group D in the Norwegian cod-fisheries, () indicates goal fulfillment.

Performance indicator	2003	2004	Change (%)
FAR	12.0	9.0	-20.65%(+)
Average number of man-labor years	25.8	27.6	7.0%(+)
Earning capacity	1.34	2.25	67.9%(+)
Catch capacity, average length (m)	61.19	61.44	0.41%(-)
Fuel consumption	0.57	0.47	-17.5%(+)
Index, D	.	.	112.64%

equally, as is the case in Table 8 and Table 9.

The percentage changes from 2003 to 2004 have to be considered in the light of the management objectives, shown in Table 1. For instance, a negative change in fuel consumption means increased goal achievement. Both indices calculated show a positive increase in sustainability. Nevertheless, an index may absorb negative developments within some attributes. Evaluation of an index may be related to establishment of acceptance criteria, as discussed in [6].

5 Discussion and conclusions

A lot of information is available about the Norwegian fisheries, but the data are not presented in a format suitable for evaluating the performance of fisheries management related to goal achievement over time. If the fishing fleets are to become more sustainable, fisheries management should be able to evaluate the effectiveness of its objectives. Use of performance indicators and indices, for example, those shown in Table 2 and Table 8, may facilitate such evaluations. In systems engineering, the process of identifying performance indicators is based on determining the requirements to the system; in this case a sustainable fishing fleet. The Norwegian fisheries management aims at reducing overcapacity through structural changes. The effects of such efforts should be monitored in order to evaluate their consequences against management objectives. Effective implementation presupposes that the efforts increase sustainability in the fishing fleets.

Evaluating sustainability in the fishing fleet is difficult, especially because the different fleets do not have the same framework conditions. Still, the results from the AHP evaluation show that the selection of attributes is very important. If the con-

cept of “sustainability” is just related to fuel consumption and biological impact, such as bycatch and selection, the smallest vessels may be the most sustainable. However, the largest vessels may be more sustainable if “accident risk” is weighted highest.

Maybe one of the most intriguing issues that came out of the stakeholder involvement, was that most of them rated the attribute “accident risk” the highest. Thus, it is a paradox that the fisheries continue to have such a high FAR value, higher than most other occupations. Even though fishing has always been an activity involving risk, it is incomprehensible that there still is such a high risk in the fishing fleet.

Government policies are often formed through intense debates and compromise. The stated goals may be a mixture of multiple and competing goals. The AHP may be used as a performance measurement instrument by incorporating assessment attributes or performance indicators into the problem hierarchy in order to compare the actual performance of a system with its desired performance. The process of using AHP in the interviews of and questionnaires to the stakeholders, has given a good foundation for further investigations of stakeholder involvement in fisheries management decision-making. In addition, this article has visualized and evaluated some important attributes of sustainability in the cod-fishing fleets, which may contribute to a better decision basis for fisheries management.

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Article 4

Can cod farming affect cod-fishing? A system evaluation of sustainability

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Can cod farming affect cod fishing? A system evaluation of sustainability

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Abstract

The cod resources in the Barents Sea constitute the most important fisheries in Norway. In order to reduce resource allocation conflicts among different gear and vessel groups and to ensure profit for all participants throughout the value chain, the sector is thoroughly organized. The institutions established to ensure long-term sustainability, have been developed within the framework of a joint Norwegian–Russian fisheries management regime. However, due to a very high fishing mortality, the cod stock is now under severe pressure. In addition, a major part of the cod fisheries is highly seasonal and unable to be a stable supplier to neither the land-based industry nor demanding international markets. In parallel, cod farming is expected to become a new emerging industry, with potential to copy the success of farmed Atlantic salmon. Many actors within the cod fisheries fear the future competition from the growing cod farming sector. With reference to important attributes that characterize the cod fisheries and cod farming, this paper discusses how a future farming industry may affect the traditional cod fisheries. Moreover, we discuss how the fisheries may be forced to organize in the future to encounter the expected competition from cod farming.

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Keywords: Cod farming; Cod fishing; Sustainability; Fisheries policy

1. Introduction

The cod (*Gadus morhua*) represents the cornerstone of Norwegian fisheries. The fleet consists of small one-man vessels with hand-line gear to modern factory trawlers producing frozen fillets onboard. The variations in technological adaptations have formed a coastal fleet characterised by highly seasonal inshore fishing, to a deep-sea fleet operating year-round in the North Atlantic.

However, the cod fisheries' significance is not only related to technological development and market orientation. Starting from the 1930s and onwards, an institutional regime has been established through legislation and organization to solve important allocation conflicts. The establishment of the Law of the Seas in 1977 facilitated an agreement for joint management of the Barents Sea fish

resources between Russia and Norway. This arrangement safeguards a stable co-operation within the Norwegian–Russian Fisheries Committee on the advice from ICES and ACFM about the annual TAC [1].¹

In Norway, there is a consensus for the institutional framework called the trawl ladder. This arrangement fixes sharing of the cod resources between the coastal fleet and the deep-sea fleet, and it secures a long-term predictability between the groups.² Further, the relationship between the fishing fleet and the processing industry with respect to pricing is governed. The establishment of a mandated sales organization in 1934 ensures the fishers a reasonable portion of the cod's market value [3].

¹ICES (International Council for the Exploration of the Sea), ACFM (Advisory Committee for the Fisheries Management), TAC (Total allowable catch).

²The trawl ladder was adopted at the 1994 national congress of the Norwegian Fishermen Organization, allocating 25–35 % of the Norwegian cod TAC to the trawlers and the rest to the coastal fleet. The lower TAC, the lower percentage share is given to the trawlers and vice versa [2].

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According to Young [4] and Libecap [5], both national and international arrangements for the management of the cod fisheries may fulfil many of the criteria for a sustainable regime. The successful organization of the cod fisheries was also what the earlier Minister of Fisheries, Jan Henry T. Olsen, had in mind when he proudly claimed that Norway is a world champion in fisheries management and that the rest of the world has a lot to learn from Norway.³

Despite the high degree of formal organization, the cod fisheries are facing serious challenges. According to the Norwegian Directorate of Fisheries [6], Russian cod trawling in the Barents Sea is out of control. Estimates of over fishing exceed 100 000 tons per year [7]. Another issue of international conflict is the protection zone for juvenile fish around Svalbard Island. Many nations contest the Norwegian claimed sovereignty around the island and there is international pressure on exploitation of the fish resources in the zone. Also in the Loop Hole, outside both Norwegian and Russian jurisdiction, there is timely a significant fishing activity by trawlers under flag of convenience, which are not restricted by international agreements. In addition, for a number of years the joint Norwegian–Russian Fisheries Commission has decided on TACs exceeding the recommendations from ICES [8].

Currently, the Norwegian coastal cod stock level is historical low. The Norwegian Institute of Marine Research (IMR) considers the situation as critical and has proposed closure of the fishery as the only solution to rebuilding the stock [9]. The serious condition of the coastal cod stock is also expressed by the fact that the certification agency Moody Marine does not recommend environmental labelling of the coastal cod fisheries [10]. Another important characteristic is that the cod fisheries are highly seasonal. Most of the TAC is landed from January to April, resulting in low catch rates during autumn [11]. Norway does not fulfil the objective of being a stable year-round supplier of cod, and the seasonal variations constrain the ability of the processing industry to adapt to both products and markets.

In parallel, cod farming is an emerging industry. Stakeholders assume that cod farming may be the new species suited for large-scale production, with potential to copy the success of Atlantic salmon [11]. In contrast to traditional fishing, cod farming allows full production control, high production predictability and development of long-term relationships to attractive markets [12]. By 2005, the Directorate of the Fisheries had allocated more than 300 licences for commercial farming. In total, this represents a substantial production volume [13].

The reference to the emerging tension between cod farming and cod fisheries in Norway, refers to the fact that global salmon farming has severely affected traditional wild-capture salmon fisheries in North America. Thus, an important question is whether cod farming may have

similar effects to the traditional cod fisheries. In the article *Why farm salmon out-compete fishery salmon*, Eagle et al. [14] explain how a series of differences regarding political organization, the constraints of the industries, type of stakeholders and characteristics of the value chains are advantageous to salmon aquaculture compared to traditional salmon fisheries. Many fishermen in Norway fear that cod farming may outcompete the traditional fisheries or force the current fleet structures and future quota regime into large adjustments.

In this article, we outline the different adaptations of cod farming and cod fisheries to their surroundings, and we discuss the various frameworks for organizing sustainable production systems. According to Scott [15] and Perrow [16], cod farming and traditional fisheries can be characterized as complex organizational structures. In this context, we discuss how the industries are organized at different levels and hereby the relationship between political goals and the degree of market orientation in the production processes. We hypothesise that cod farming has many competitive advantages that may seriously threaten the traditional fisheries. Based on our evaluation, we discuss how the fisheries sector may be forced to reorganize to compete against the alternative production system of cod farming. Such reorganization may cause new allocation conflicts between the ocean-going fleet and the coastal fleet, and may also challenge the established management system.

2. The concept of sustainability as analytical framework

Sustainable development and sustainability are complex concepts, which are difficult to apply and define. Sustainability cannot be investigated within the limits of a single scientific discipline, because it involves several disciplines, such as ecology, economy, engineering, law, physics, politics, and sociology. This multi-disciplinarity introduces cross-disciplinary communication problems, which causes conceptual difficulties and unclear measures of sustainability [17]. The scientific disciplines may be reflected in the dimensions of sustainable development: The social, environmental, and economic dimensions. Some authors also add institutional sustainability to this list, e.g., UN's FAO [18]. The sustainability dimensions are reflected in the crucial attributes used in the following assessment and discussion of cod fisheries and cod farming as production systems, shown in Fig. 1.

In Fig. 1, the strong lines indicate a positive relationship or an advantage between the attributes and the production system, whereas the weak lines indicate disadvantages. There is no weighting or ranking between the attributes, which means that the figure does not reflect if any of the attributes should be considered more important than the others.

Hohmeyer et al. [19] claim that a production is economically sustainable when it is profitable in the long run without input from the public in the form of monetary

³The Minister of Fisheries speaking to the media during the negotiations about EU-membership in 1993.

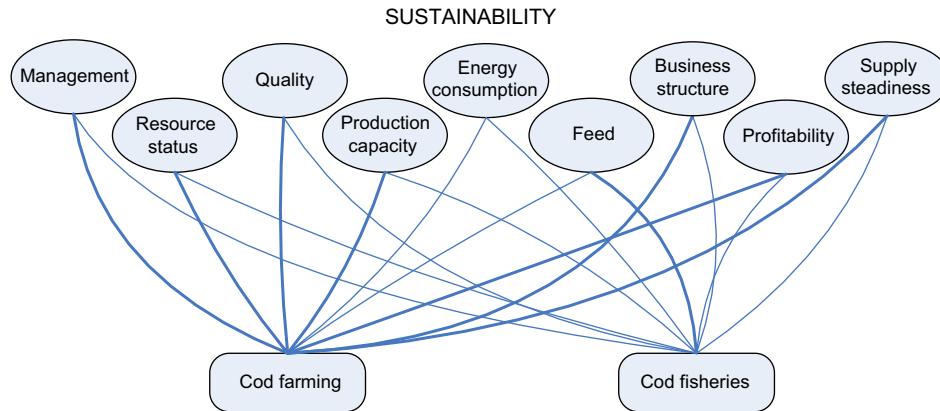


Fig. 1. Attributes of sustainability when comparing cod farming and cod fisheries.

subsidies, or when the industry is successful without imposing costs to the public. An industry is environmentally sustainable if it maintains, or is part of a management system that maintains, the natural capital which it depends on. In the case of renewable resources, such as fish stocks, maintenance means not impairing the ability of the resource to provide service from generation to generation.

Institutional or political sustainability is seen as part of the constraints or framework conditions for the fisheries and aquaculture industry. According to Galasso et al. [20] political sustainability is measured by the extent to which an industry is vulnerable to, or dependent on, political intervention. An industry that faces substantial public criticism is less likely to persist in the long run than the one that is not. Similarly, an industry that requires repeated political interventions, e.g., disaster relief appropriations, in order to prosper, is less likely to persist than the one that does not. The dimensions of sustainability are often interconnected, e.g., industries that impose costs on society through e.g. pollution (economically unsustainable), are likely to attract unwanted attention from the political processes (politically unsustainable). With reference to the complex surroundings for both fish farming and traditional fisheries, we sort out the general concept of “sustainability” into some attributes that are crucial for fishing and farming.

3. An evaluation of sustainability attributes

The TAC for the Norwegian–Arctic cod stock has varied from 1 million ton in 1974 to about 200 000 tons in 1990 [21,22]. On advice from ICES, biological reference points have been introduced in order to safeguard sustainable management of the cod stock by restricting fishing mortality (F_{pa})⁴ [24]. However, in 11 out of the last 14 years, the joint Commission has decided on a higher TAC than the recommendations from ICES [25]. The most dramatic overexploitation occurred in the years 2000 and

2002. In 2000, ICES recommended a TAC of 110 000 tons, yet the actual catch was 414 000 tons. In 2002, ICES recommended a TAC of 181 000 tons, but the actual catch reached 535 000 tons. Thus, the fishing mortality has been much higher than recommended. The TAC for 2005 was 485 000 tons, and the illegal fishing of 100 000 tons represents more than 20% of the TAC [6]. For the year to come (2007) the trend of ignoring recommendations from ICES seems to continue; while ICES have proposed a TAC of 309 000 tons, the Norwegian–Russian Fishing committee are landing on a TAC of 424 000 tons [26].

Today, there is no consensus between Russia and Norway regarding the level of fishing mortality (F). Russia is totally ignoring the Norwegian authorities’ estimations of the Russian overfishing. Hence, there is an intensive political process between Norway and Russia in order to gain control of the unregulated fishing that threatens the whole management of the cod stock. In addition, there are several court trials as a result of illegal fishing by international trawlers in the Protection Zone outside the Svalbard Island [27]. The political disputes and lack of institutional sustainability may reduce the cod stock to a level below ICES’s minimum biological requirements.

The debate about system failure within fisheries management linked to over fishing and unprofitable overcapacity, is not found in the discussions about future expectations of cod farming. On the contrary, cod farming is considered positively with no negative public attention, with potential to copy the success from the salmon aquaculture industry and create new corporate activity in fishery dependant rural areas [28]. In Norway, farming cod has moved from an early phase with main focus on research and development, to commercial production. In 2005, there were 5500 tons of farmed cod in Norway, a tripling from the year before. In the years to come, it is expected that the production may increase to 20 000 tons [29], and optimistic predictions claim a quantum of 150 000–200 000 tons by 2010 [30]. In 20 years, it is expected that cod farming may contribute to a value creation of 10 billion NOK [31].

On the other hand, fish farming is dependent on secure supplies of feed. Thus, the whole aquaculture industry

⁴Fishing mortality precautionary approach (F_{pa}): For the Barents Sea cod, the F_{pa} is set to 0.42 to maintain a sustainable stock [23].

needs increased development and documentation of a wider range of sustainable raw materials for cost-efficient feed production. Even though vegetable sources may be an alternative feed source in the future, fish farming today is dependent on marine feed. Feeding wild fish to farmed fish implies that some of the problems related to the capture fisheries are also relevant to the aquaculture industry [32]. The environmental impacts from catching and farming of fish, processing and transport to the markets are receiving increased attention from strong consumer groups and retailer organizations. Ellingsen and Anondsen [33] have shown that the energy use in salmon aquaculture and cod fishing by bottom trawling is almost equal, and in comparison with chicken, fish is more energy intensive.

A substantial part of the fish feed used in salmon aquaculture is based on wild caught fish, which means that high energy use in the fisheries contribute to a high energy consumption in aquaculture [33]. In general, fish feed for cod contains more fish meal and fish oil than salmon [32], but it has been shown that cod do not develop enteritis when soybean meal is included at high levels in the feed, which is promising [34]. A higher level of marine feed in the fish feed may imply a higher energy consumption than for salmon feed.

The type of ownership and business structure in cod farming are fundamentally different to the predominant coastal fisheries. In cod farming, there are no legislative restrictions linked to the type of ownership and the new industry is dominated by institutional investors with long-term financial power. Efforts are made to form larger production units to gain economies of scale and to better coordinate production and marketing strategies [35]. In contrast, the cod fisheries are dominated by smaller vessels and seasonal adaptations to the cod's migrating pattern. According to both the land-based fish industry and fish traders, the lack of stability in the supply chain makes the industry vulnerable and unable to be a stable supplier to the best paying markets. With reference to political decisions, the coastal fishing fleet is given the largest proportion of the Norwegian cod TAC. However, the inherent seasonality causes problems between the catching and processing segments by limiting the opportunities for utilization of cod as raw material [36]. For the processing industry, it is difficult to invest in costly equipment and adapt the processing capacity to high seasons. Thus, a considerable amount of the catch is exported as raw material or commodity products such as salt fish and stockfish [37].

However, for sustainable development of the cod farming industry, the relationship between production costs in regard to gross income are crucial elements. With reference to salmon farming, the production volume of Atlantic salmon was more than 50 000 tons in 1985 and this increased strongly in the 1990s. In 2004, the annual production volume exceeded 600 000 tons [38]. In parallel, the average costs per produced kg of salmon decreased greatly, from an average of 60 NOK in 1985 to 26 NOK in 1994. By 2004, production costs had diminished to 15 NOK

per kg. According to the Norwegian Fisheries Directorate's annual economic analyses of the aquaculture industry, there are actors producing salmon at costs of about 10 NOK per kg [13]. The decrease in production costs is due to improvements in fish farming through better knowledge of breeding and genetics, the introduction of vaccines, new feeding regimes and general improvements in the biology and technology conditions [39]. Cod may have the same potential for increased effectiveness in terms of cost reduction as farmed salmon.

Based on the price elasticity of cod in the world markets, the volume of fish produced in the aquaculture industry may cause a price decline, especially if the cod prices follow a similar pattern as the Atlantic salmon. Vassdal [40] shows that a production volume of 50 000 tons of farmed cod may reduce prices and cause economic loss for both fishers and farmers. Hence, the decline in prices, following increased production, may be the greatest challenge to industrial commercialization of cod farming. Thus, the future of cod farming is heavily dependant on increased cost efficiency from improved production, principally through better breeding and lower feed costs.

Fig. 2 shows the expected development of the production costs, with increasing profitability creating a basis for profitable production and increased volume (tons). Presently, it is assumed that the income and the production costs are break even per produced kg of cod [41].

Today, the main advantage for traditional fisheries is that the cost per kg of fished cod is substantially lower than the production cost for farmed cod. The annual Norwegian TAC in the Barents Sea is about 200 000 tons of cod. Thus, 50 000–100 000 tons of farmed cod represent a considerable contribution to the total supply. Further, farmed cod can be provided to at the market during autumn when the traditional fisheries are in the low season. In this way, cod farmers may coordinate their production to the great variations in the traditional fisheries, in order to achieve higher prices than the fishers do during winter time.

Fig. 3 shows that from January to April, the landings of cod are the highest, with the highest prices paid per kg cod during the fall.

In 2003, the Norwegian cod TAC in the Barents Sea was 195 000 tons, with 72% of the quota allocated to the coastal fleet. Almost 150 000 tons of the TAC was caught during January–May; a result of the large seasonal variations, but also caused by the management regime itself. The coastal fleet is managed through an individual vessel quota-system (IVQ) based on vessel length. Experiences have shown that the smallest vessels do not fish their quota, while bigger coastal vessels have the capacity to fish more than their allocated quotas. This situation has caused an “overbooking” of the quota system. In practise, the coastal fleet with licences to fish cod has had few restrictions within the framework of the coastal vessels group-quota, creating a race for fish and increased seasonality [42].

If we look closer at the distribution of cod quotas over a longer time perspective, shown in Fig. 4, vessels

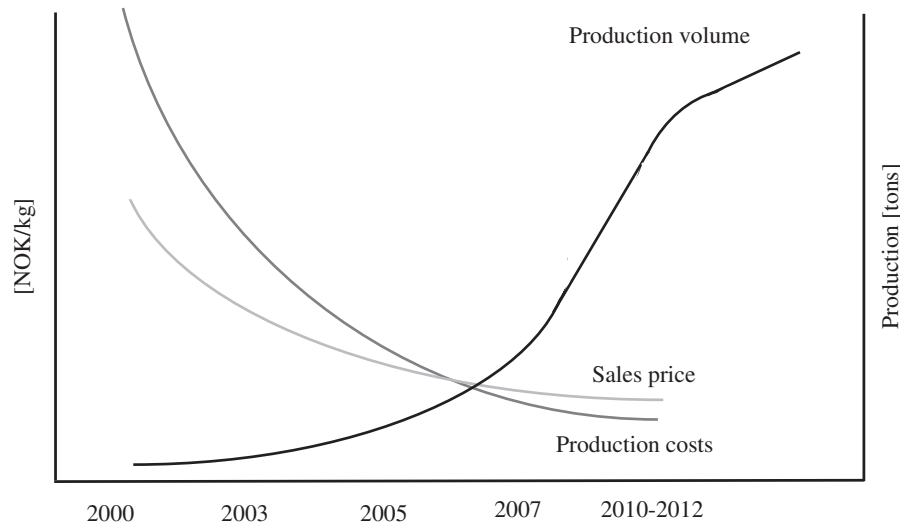


Fig. 2. Anticipated development of sales price, production costs per kg and production volume (tons) for farmed cod, 2000–2012.

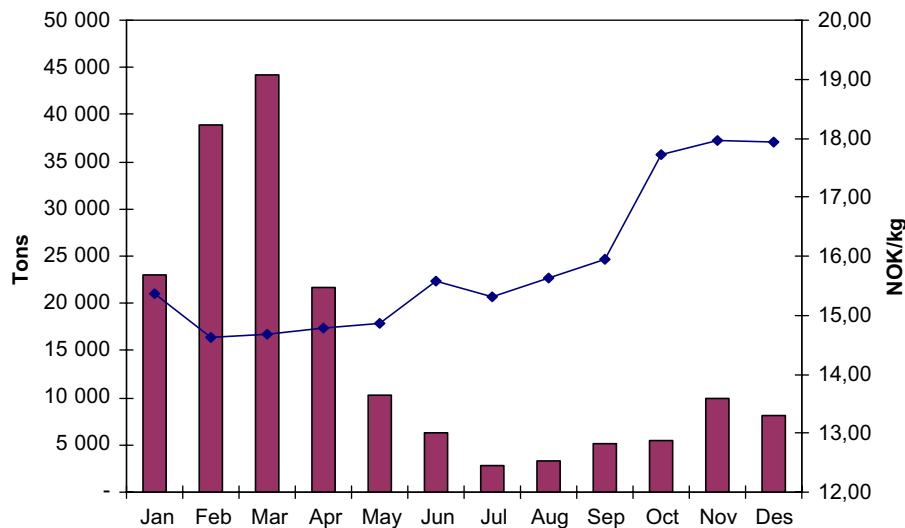


Fig. 3. Total Norwegian cod catch (tons) and prices per kilo NOK, 2003 [30].

fishing with gill nets are allocated the largest share of the quotas, and these have a marked seasonal peak catch in March and April. Other gear groups, such as trawl and Danish seine, have smaller variations in catch throughout the year. In recent years, the need for increased fish quality handling on board has been a high priority. However, analysis of the relationship between fish quality and the use of different fishing gears, indicates that gill nets may give the worst quality among all traditional fishing gears [43].

Recently, there has been a change in the quota regime for the coastal fleet. Due to unprofitable overcapacity, the Ministry of Fisheries decided that vessels between 15 and 28 m may concentrate up to three quotas per vessel [44]. This arrangement has strengthened the operating basis for the remaining vessels. Unfortunately, the seasonal nature of the fishery has increased at the same time. Half of the registered coastal vessels with licence for cod fishing, also

fish herring, mackerel and saithe. These fisheries are seasonal as well, which means that it is important to finish cod fishing during winter in order to participate in the other fisheries later in the season.

The seasonal fluctuations of the cod combined with a high state of competitiveness and dependence on other seasonal fisheries, force the fishers to focus on quantity at the expense of quality. The landing of large quantities of catch in a limited time period reduces the quality of the fish, causing financial loss for the fishers and the processing industry [37]. Thus, it is the organizational structures that limit alternative fishing strategies or the system imperative that create the large seasonal variations and generate considerable interaction problems and transaction costs throughout the value chain.⁵ In contrast, the cod-farming industry has far better opportunities to deliver fish of high

⁵For a discussion about transaction costs, see [45,46].

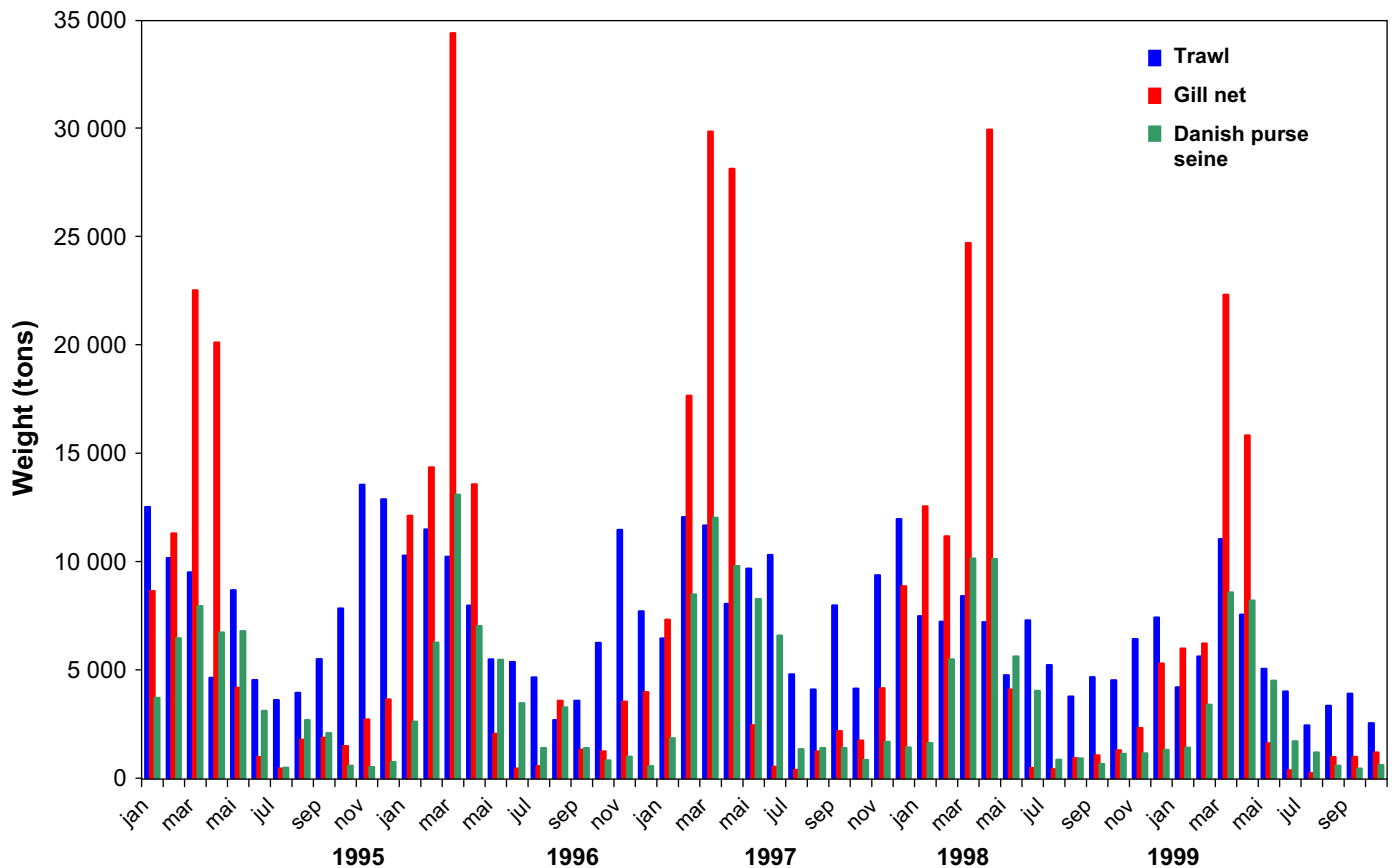


Fig. 4. Catches of cod distributed between trawlers, gill netters and Danish purse seiners, 1996–1999 [30].

quality to the markets through more effective logistics and traceability.

4. Discussion

This article has compared some attributes of sustainability between the cod fisheries and cod farming, summed up in Table 1.

The evaluation shows that the traditional cod fisheries face several important challenges, including (1) the uncertainty related to the resource situation following the institutional weaknesses in the management of the cod stocks in the Barents Sea and; (2), the great seasonal variations related to end markets; and (3) competitive challenges from the emerging cod-farming industry. From this perspective, the traditional cod fisheries no longer only face complex issues related to fisheries management, fishing gear technology, and internal economics. From now on, the fisheries must also deal with a new and alternative production system, which lies outside the traditional decision-making arena.

However, cod farming is also heavily dependent on positive attention from legitimate stakeholders holding a variety of perspectives on fish farming. In order to be politically and economically sustainable in future, cod farming must be environmentally sustainable

Table 1
Evaluation of the sustainability attributes

Attributes	Cod fisheries	Cod farming
Management	Instability	Stability
Resource status	Overfishing	Emerging
Quality	Varying	High
Production capacity	Overcapacity	Unlimited
Energy consumption	High	High
Feed situation	Unlimited	Limited
Business structure	Several, fragmented	Few, large companies
Profitability	Low	Emerging
Supply steadiness	Unstable, bottlenecks, transaction costs	Stable, predictable

within the regulatory framework. Fish farming must be economically viable and yet also control escapes of fish to avoid interbreeding with wild fish, which may lead to genetic degradation [47]. Other problems may include spreading of diseases and parasites from farmed fish to wild fish and the use of antibiotics to cure bacterial diseases [48].

As discussed, it is reasonable to believe that cod farming may cause future economic loss to the fisheries by the future increase in the volumes of cod and an anticipated price decline. Such a situation will probably demand

introduction of new political and management measures to increase profits in the fleet. New allocation conflicts between different vessels and gear groups may occur, challenging the established quota system, based on individual vessel quotas (IVQ). Due to technological change and unprofitable overcapacity, the need for capacity reduction has been constantly on the agenda since the end of the 1980s [49]. The level of conflict between the fishers has been high. When the cod fisheries more or less collapsed in 1990–1991, the Ministry of Fisheries proposed the introduction of individual transferable quotas (ITQ) as an attempt to remove overcapacity [22]. After a public enquiry, the proposition was rejected by the entire fishing segment and the Ministry of Fisheries had to withdraw the proposition. Since then, the fisheries management has been forced to solve the problems of overcapacity, within the framework of the existing IVQ-system. However, the quota system has been subject to market-orientated changes in regard to transactions of quotas, reductions in the number of vessels and increased quota concentration among fewer vessels.

Holm et al. [50] and Hersoug [51] describe the Norwegian IVQ-regime's stepwise changes towards an ITQ-system as a result of path dependency. From 1990 and onwards, the quota-system has changed within the framework of an IVQ-system from a rigid regime with no flexibility in terms of quota transactions, to a system that gives the fishers the opportunity to concentrate up to three quotas per vessel on an on-going basis. This arrangement has led to tremendous amounts of quota transactions and large structural changes both in the coastal and deep-sea fleet. However, the system has also led to an increased capitalization in terms of investments in cod quotas [52].

Strong critics claim that the liberalization of the original IVQ-system has caused too great a concentration of quotas. They demand that the development towards an ITQ-system has to be stopped. Today in Norway, there is no consensus about the future path for the quota regime [53].

As a comment to this debate in Norway, the average catch value of traditional wild salmon fisheries in Alaska, were reduced by 36–82% from 1988 to 1992. Following the price decline after the rise of salmon aquaculture, the ex-vessel value of the salmon fisheries declined from more than US \$ 700 million in 1988 (240 000 tons landed) to about US \$ 160 million in 2002 (283 000 tons landed). Thus, the market value of fishing licences, which also restricted the number of fishers, is drastically reduced. From 1993 to 2002, the licence value was reduced by 79% or US \$ 700 million. The strong decline has negatively impacted the Alaskan society, especially in small rural villages heavily dependent on income from the salmon fisheries [14].

The experiences from Alaska show that the increased volume of farmed salmon contributed to a price decline, as well as a strong decline in licence value causing a financial loss in quota rights transactions. A similar development

between cod farming and the cod fisheries may challenge the Norwegian quota regime towards a further market-based system. Cod farming may be the external factor that forces a shift from a modified IVQ-system to an ordinary ITQ-system. Hence, the debate about quota regimes and allocation processes is no longer an internal matter for the established corporative channel between the fishers' organizations and the state authorities. In the future, these issues will be challenged by the emerging farming industry outside the traditional fisheries segment.

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Article 5

Life cycle cost (LCC) as a tool for improving sustainability in the Norwegian fishing fleet

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Article 6

Acceptable sustainability in the fishing fleet

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Acceptable sustainability in the fishing fleet

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Abstract

This article discusses the performance of the Norwegian fishing fleet within an acceptable level of sustainability. Previously, the cod-fishing fleet has been evaluated at the attributes-accident risk, employment, profitability, quality of the fish meat, catch capacity, greenhouse gas emissions/acidification, and bycatch/selection. The assessments focused on the first four steps of the systems engineering process, i.e., from needs identification to trade-offs of system alternatives. The objective of this paper is to focus on the last steps of the process; design, solve, verify, and test, to improve the decision-basis for fisheries management in order to increase sustainability in the fishing fleet. More specifically, this means to analyze the decision-making situation and develop acceptance criteria of a sustainable Norwegian cod-fishing fleet to enable fisheries management to monitor the sustainability performance of the fleet on a regular basis.

Key words: Sustainable fisheries, systems engineering, acceptance criteria

1 Introduction

Fishing has always been a prerequisite for the coastal settlements in Norway, and is by far more effective now than a few decades ago. The technological improvements in catching gears and fishing vessels facilitate a larger quantum of fish caught per fisher. Norway has a differentiated fishing fleet with respect to size and type of catching gear; from small conventional coastal vessels to large ocean-going factory trawlers. Sustainable management of renewable resources, as well as safeguarding coastal settlements, are fundamental in Norwegian fisheries policies [1]. Nevertheless, parts of the Norwegian fisheries are not sustainable. Moody Marine Ltd. did not recommend Marine Stewardship Council (MSC) certification of the Norwegian

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coastal cod and haddock fishery based on the serious condition of the fish stock [2]. Another prevailing problem is overcapacity in the fishing fleet. In the last decade, the number of fishing vessels has been reduced, but the catch capacity of the vessels has increased [3].

Today, the main input to fisheries management are biological assessments of the fish stocks and economic information about profitability in the fisheries. The technological development in the fishing fleet and the persistent problem of overcapacity imply that there is a need for a technological perspective as well. Systems engineering has been introduced as a feasible process for handling sustainability issues in the fisheries [4, 5]. Systems engineering is defined by The International Council on Systems Engineering [6] as “an interdisciplinary approach and means to enable the realization of successful systems”. A system can be described as an organized and structured totality of parts, such as natural physical and biological systems, and for social, commercial, and political forms of organizations. Thus, systems engineering is an interdisciplinary approach that contains methods and procedures for general system design, operation, and support.

The systems engineering process is based on the common sense strategy of understanding a problem before solving it, evaluating alternative solutions, and making sure that the chosen solution is correct before realization. The basic process tasks are iterative, but consists of the six steps [7, 8]:

- Identification of system stakeholders and needs
- Definition of performance requirements
- Specification of system performances
- Analysis and optimization of the system (alternatives)
- Designing and solving
- Verification and testing of the system

Further description of the systems engineering process may be found in [6–10].

The performance of the Norwegian cod-fishing fleet has been evaluated at seven attributes of sustainability [5]. The attributes are accident risk, employment, profitability, quality of the fish meat, catch capacity, greenhouse gas (GHG) emissions/acidification, and bycatch/selection. The assessments focused on the first four steps of the systems engineering process, i.e., from needs identification to trade-offs of system alternatives. The objective of this paper is to focus on the last steps of the process; designing and verification, to improve the decision-basis for fisheries management in order to increase sustainability in the fishing fleet.

The first part of the article discusses the evaluation process of systems engineering. Then the concept of acceptance criteria is elaborated as means of evaluating the sustainability performance of the fishing fleet. The last part of the article discusses and proposes a criterion for each of the the attributes. These criteria can be used to assess whether the fishing fleet is sustainable according to government

objectives or not. It is concluded that quantitative criteria are possible to establish for accident risk and GHG emissions/acidification, and qualitative criteria for the other attributes, but in the end the criteria are dependent on political objectives and trade-offs.

2 Designing and solving, verification and testing

The systems engineering process may be applied to a wide variety of issues in the fisheries, not only to the design of technological systems for fishing vessels, but also in the development of strategies for fisheries management [4, 11]. In the process of system development, there are many decisions to be taken involving trade-offs related to selection of the most suitable technologies, materials, maintenance routines, support policies, manufacturing processes, logistic structures and so on. The trade-off analyses lead to the system design. Early in the process, preliminary concepts are developed to establish the connections between the system components. When the functions to the system have been decomposed, design involves configuration of the components and the final system form, even though modifications may still be done. When the system is configured, it has to be evaluated based on the system requirements specified. This is an iterative process, because changes to the system configuration may be necessary, until the preferred solution is found [10].

Evaluation and testing of the system begins when the conceptual design is developed, endures through the operational phase of the system, and ends when the system is retired. The objective of evaluation is to make sure that the system fulfills its intended purpose. The requirements to testing, and choice of test and evaluation method, should be determined when the overall requirements to the system are established. The issue at stake is how to make sure that the requirements to the system are met. For products, in the preliminary system design, analytical testing may be applicable. Analytical testing may be facilitated by computer programs, for example by modeling the design in a three-dimensional view that shows size of components, interferences, and so on. Later in the process, mock-ups and prototypes facilitate physical testing which makes evaluation more effective. The best circumstances for testing is when the system is fully operational, but taking corrective action after the equipment is produced can result in expensive modification programs. Thus, testing at different levels of detail during the systems engineering process is more cost-effective [12].

For fisheries management, new regulations (with a few exceptions) are subject to public inquiry by stakeholders involved, i.e., public and private institutions and organizations [13]. In this way, the perspectives of the stakeholders are integrated, even though compromises have to be made. Public inquiry is one type of evaluation before implementation. Another way for fisheries management to evaluate the

effects of new regulations, is to restrict it to a limited region or time period. After a test period, the consequences of the regulation are evaluated, before deciding whether to implement or reject it.

When the requirements to the system are developed, possibly by describing the functions to the system, it is necessary to review the requirements in terms of degree of importance and their interdependency. Is the speed of the fishing vessel more important than the fuel consumption? For the communication system, is range more important than reliability or clarity? Requirements are often expressed in very general qualitative terms, so the question is how to measure the test results for validation of the system? The objective may be to design the system in accordance to consumer or stakeholder requirements, but unless there is very good communication between the stakeholder and the system designer, quantitative measures or “system metrics” should be established. These metrics can be called performance indicators [7] or technical performance measures (TPM) in the systems engineering process [12].

The system may be required to comply with specific standards to assure a minimum quality performance. Regarding Norwegian fishing vessels, there are for example requirements to the construction, operation, and equipments [14]. Vessels with length $\ell > 15m$ are subject to inspections by the Norwegian Maritime Directorate, whereas vessels with length $\ell < 15m$ are subject to internal control and control by authorized consultants [15]. Environmental performance of organizations and businesses may be specified by adopting an environmental management system, as provided by the ISO 14000 series [16].

3 Acceptance criteria

Decisions are made in every part of a system’s life cycle. Every decision involves analysis and trade-offs of alternative options [6]. In order to evaluate whether or not the alternatives fulfill the system requirements, acceptance or fit criteria may be applied. The criteria may be used to determine if the system passes the requirements or not [17]. Robertson and Robertson [18] describe the fit criterion as the specification of the requirement, derived by determining the quantification that best expresses the stakeholder’s need. Requirements based on needs may often be ambiguous, for example, “the fishing vessel shall have an energy efficient engine”. A fit criterion specifies the required fuel consumption of the engine, whereas the performance indicator measures the actual fuel consumption of the engine. As a matter of form, the term “acceptance criteria” is used in the rest of the article.

Acceptance criteria clarify the requirements and may therefore contribute to consensus among many stakeholders. Most often they are derived after the system requirements are determined. In many cases it is an advantage if the criteria are

Table 1

Sustainability attributes and performance indicators that may be used by fisheries management to evaluate the Norwegian cod-fishing fleet, based on [5].

Attributes	Performance indicators
Accident risk	$I_1 =$ Risk, fatal accident rate (FAR) ^a
Profitability	$I_2 =$ Earning capacity NOK/kg fish catch
Employment	$I_3 =$ Average number of man-labor years/vessel
Quality of the fish meat	$I_4 =$ Quality, income loss due to damaged fish (NOK)
Catch capacity	$I_5 =$ Catch capacity; aggregated measure of the vessel capacity parameters, [3]
GHG-emissions/acidification	$I_6 =$ Fuel kg/kg fish
Bycatch/selection	$I_7 =$ Amount of species caught as bycatch, tonnes

^a The FAR value is defined as the mean number of fatalities per 10^8 exposed hours.

shown as a range. A range would deter the developers from making the product or system very expensive, just to make sure that it fulfills the criteria. A range opens for trade-offs in selecting the best design to fit the design constraints and the budget [18]. An example of a such a range is the ALARP (As Low As Reasonable Practicable) principle, further discussed in the next section.

3.1 Acceptance criteria for sustainability in the Norwegian cod-fishing fleet

The performance indicators (found in Table 1) may be used to measure sustainability in the fishing fleet on a regular basis. These indicators are selected based on government objectives to sustainable resource management, and are the quantitative representation of the sustainability attributes. To be able to interpret the changes in the performance indicators, that means to evaluate whether the sustainability of the fishing fleet is increasing or decreasing, and to determine the distance between the performance level and the desired objective level, acceptance criteria may be defined.

FAO [19] uses the term reference points instead of acceptance criteria. A reference point describes a particular state of a fisheries indicator compared to a situation considered as desirable, or undesirable and requiring immediate action. The reference points are related to human objectives or system constraints, and provide

information needed to evaluate the situation and a bridge between objectives and actions.

3.1.1 Acceptance criteria for accident risk

The accident risk level in the fishing fleet should be compared with other industries, such as the petroleum sector and the mining industry [20]. To manage risk in the Norwegian oil and gas industry, it is common to use risk acceptance criteria [21]. According to Rausand [22], acceptance criteria may be defined as “criteria based on regulations, standards, experience and/or theoretical knowledge used as a basis for decisions about acceptable risk”. Acceptance criteria may be expressed verbally or numerically. A risk acceptance criterion may be: “The FAR value should be less than 10 for all personnel on the installation, where the FAR value is defined as the mean number of fatalities per 10^8 exposed hours” [23]. The acceptance criteria may also be stated as potential loss of life (PLL), by using risk matrices, or f-N curves. FAR and PLL are quantitative scales, risk matrix is a semi-quantitative method which evaluates different risk scenarios and potential outcomes in a systematic way. f-N curves (f= frequency, N=Numbers) express the acceptable risk level as a curve with various frequency (for, e. g., fatalities) compared to various consequences (for, e. g., number of deaths). In the Norwegian oil and gas industry, risk acceptance criteria should be based on [23]:

- Safety regulations
- Approved norms for the work operations
- Requirements to risk reducing efforts
- Knowledge about accident events and effects
- Experience from own and equivalent industries

Risk analysis is used to confirm that the risk acceptance criteria are met so that the need for risk reducing measures can be determined. The criteria should be specified before alternatives are generated and evaluated [24]. “Acceptable risk” problems are solved by relating the acceptance criteria to the ALARP principle [25], which means that the risks should be reduced to a level as low as reasonably practicable. Usually, cost-benefit analyses and cost/effectiveness analyses may determine if a risk reducing effort is reasonable. Together with ALARP, a limit for intolerable risk and a limit for negligible risk are usually defined. The interval in between these is often called the ALARP region [21], shown in Figure 1. The ALARP principle is not an acceptance criterion in itself, but a way of thinking [26].

Aven and Vinnem [21] present perspectives for not applying risk acceptance criteria in the petroleum offshore industry, because pre-determined criteria may cause too much focus on meeting these criteria instead of obtaining overall good and cost/effective solutions. Another issue is that the risk analyses used to verify that the criteria are met, are not precise enough for that kind of use. The solution to these

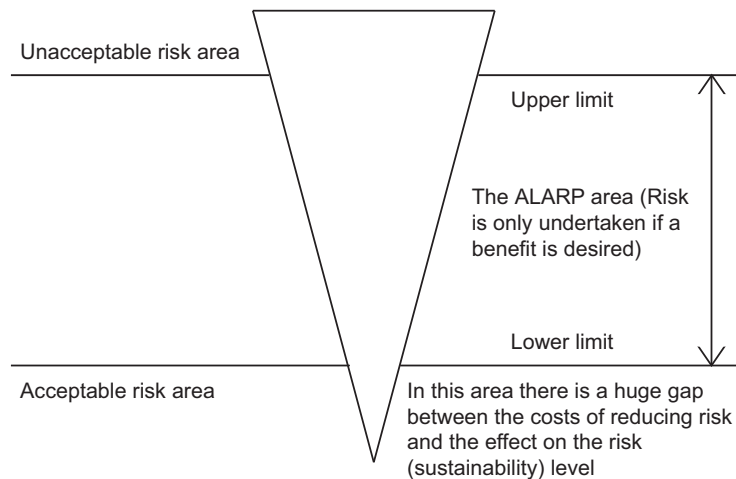


Fig. 1. The ALARP area. From the Norsok Standard Z-013N [23] and [27].

problems may be to put more emphasis on the ALARP principle, more in line with how the UK sector has adopted it. Focus should be on identification of alternatives and evaluation of these to facilitate decision support, by balancing the advantages and disadvantages of the alternatives. The ALARP principle is also controversial, for example, the time horizon may influence the cost analyses. Another discussion is whether use of acceptance criteria are consistent with some decision theories or not. Abrahamsen [24] concludes that acceptance criteria are inconsistent with the expected utility theory and the rank-dependent utility theory, due to violation of the independence axiom of the methods.

SINTEF Fisheries and Aquaculture [28] has registered 105 fatal accidents in the Norwegian fishing fleet from 1997-2006, an average of approximately 10 fatal accidents every year. This is much higher than similar industries, such as farming, forestry, the petroleum sector, and mining. In 2006 there were 4 fatal accidents in farming and forestry, out of a total employment of 63 000 [29, 30], and no fatalities in the petroleum industry and in the mining industry out of respectively 31 000 and 4000 employees [29, 31]. In the fishing fleet, 12 fatal accidents were registered out of 11 061 employees [28, 32]. Table 2 shows that the smallest vessels have most accidents, and that shipwrecking is the most important cause.

In 1986, the accident risk and safety problems in the fishing fleet were evaluated by a Norwegian official report [20]. At that time, an average of 32 persons died each year in occupational accidents. The report stated that the average number of fatalities should be comparable to other industries, such as ship transportation, the petroleum industry, and mining industries, suggesting that the expected number of fatalities should be 9 with the 1984 level of employees.

Table 3 shows that in 20 years the number of fatalities in the fishing fleet has been reduced by 60-70%, whereas the number of employees has been halved. Based on the recommendations from the 1986-report, it would be reasonable to expect that the accident risk level in the fishing fleet should be about 4-5 fatalities a year.

Table 2

Categories of fatal accidents in the fishing fleet from 1997-2006. Based on [28].

Type of accident	Vessels, $\ell < 13,5m$	Vessels, $13,5m < \ell < 27,9m$	Vessels, $\ell > 28m$	Total
Shipwrecking	28	3	2	33
Man overboard	20	3	7	30
Drowning in harbour	9	15	3	27
Hit/crunch	5	3	2	10
Falling object	0	0	4	4
Fire/gas leak	1	0	0	1
Total	63	24	18	105

Table 3

Fatal accidents and employees, 1980-1984 and 2001-2005, own calculations based on statistics from [20, 28, 33].

Time period	Fatal accidents	Man-labour years (1984 and 2005)	Mean catch/year (1000 tons)
1980-1984	156	19233	2 240
2001-2005	42	9117	2 580

However, the risk level, for example, in the oil and gas industry has also been reduced since the 1980's [34], indicating that an "acceptable" number of fatalities in the fishing fleet should be even lower.

The statistics also show that the number of fatal accidents are not equally distributed among the different vessel groups. Table 4 shows that the smallest vessels are the most dangerous. Due to the fact that 67% of the smallest vessels ($6m < \ell < 10,67m$) in the coastal fleet were reported to have critical safety defects in 2005, the Norwegian Maritime Directorate is now considering the following efforts to increase safety [35]:

- Information campaign in the fisheries industry
- Introduce two year mandatory self certification and increase the number of unannounced inspections
- Introduce requirements to initial inspection when constructing

Table 4

Risk for the cod-fishing vessel groups, 1998-2005, own calculations based on statistics from [28].

Vessel type, ℓ	FAR
$\ell < 15m$	168
$15m < \ell < 27,9m$	40
$\ell > 28m$ (Auto-lining)	12
Factory trawlers	9
Cod trawlers	18

- Introduce requirements to integrated emergency stop-device in hauling equipment and other rotating machinery
- Introduce vessel instructions and periodical control of the vessels

To which extent and when these efforts may be introduced, are not determined yet, but costs and resources have to be evaluated [35]. Twenty years ago, similar areas of priority were discussed in the Norwegian official report [20]. Since then, the number of fatal accidents has been reduced, but the socio-economic costs are still high due to the high number of occupational accidents. In comparing the benefits of the measures to prevent risk against the costs of the measures (cost/benefit analysis), there should be a “gross disproportion” between the costs and the benefits, skewing the balance towards the benefits, if measures are not to be implemented [36]. In the case of the fishing fleet, the many accidents indicate that the authorities should allocate more funds to reduce the risk level.

3.1.2 *Acceptance criteria for profitability, employment, quality of the fish meat, catch capacity, and bycatch/selection*

Table 5 shows the performance indicators and suggested acceptance criteria, based on [5, 19]. For these indicators, it is difficult to quantify and define specific criteria, because their definition depends on political decisions. Sustainable levels of employment and profitability, for example, depend on whether the government prioritizes the small fishery-dependent coastal communities through enforcing structural regulations, or if the fishing fleet structure is to be determined by market forces by an individual transferable quota (ITQ) system [37]. A quantitative criterion for quality of the fish meat is difficult to establish because there is little detailed information available on income loss related to low quality. There is statistics available on fish prices (e.g., The Norwegian Fishermen’s Sales Organisation), but these do not necessarily reflect the quality of the fish meat.

Table 5
Acceptance criteria for the Norwegian fishing fleet.

Attributes	Acceptance criteria
Employment	Historical level, policy target
Profitability	Historical level, policy target
Quality of the fish meat	Historical level, as low as possible
Catch capacity	Historical level, policy target
Bycatch/selection	Historical level, as low as possible

Establishment of acceptance criteria for bycatch/selection depends on type of fishing gear and species, because some species are threatened due to bycatch, others are not. The most serious bycatch problem in longlining is seabird impact, but a bird-scaring line may reduce this problem. Selectivity is dependent on the hook and bait. Bottom trawl is another gear with selectivity problems used in the cod-fishing fleet, but use of grid systems may reduce the catch of undersized fish. A very selective gear is gillnet, because the biggest fish are too large for the mesh opening, whereas the smallest fish swim through the mesh [38, 39].

A fishing vessel's catch capacity and utilization of capacity may be measured in economic and technical terms [40]. FAO [19] suggests that the reference point should be based on a policy target level or effort of Maximum Sustainable Yield (MSY). MSY is the highest yield (in theory) from a stock that can be harvested under existing environmental conditions without affecting the reproduction process, but this is difficult to assess. Historical levels of catch capacity may be a more feasible method to evaluate if the fleet's catch capacity increases or decreases, in line with Standal [3].

3.1.3 Acceptance criteria for greenhouse gas emissions/acidification

From 1990-2005 the Norwegian GHG emissions have increased with 8,5%. The industry, oil and gas sector, and road traffic are the largest contributors with respectively 29 %, 25 %, and 18 % of the emissions, whereas the fishing fleet was responsible for 2,3 % of the emissions. Norway is committed to the Kyoto protocol, which means that the emissions in the time period from 2008 to 2012 shall not exceed the 1990-level by more than 1 %, a 6,9 % reduction from 2005. In 1990 the Norwegian emissions were 49,8 million tonnes of CO₂ equivalents, and about 80% of the GHG emissions are CO₂ [41].

Norway is also committed to the Gothenburg protocol. Table 6 shows that Norway has to reduce the annual emissions of NO_x to a maximum level of 156 000 tons

Table 6

Norway's commitments to the Gothenburg protocol, and total emissions in 2005 [42].

	Commitments from 2010 (tons)	Emissions, 2005 (tons)	Reduction, 2005-2010 (%)
SO ₂	22 000	2400	8%
NO _x	156 000	197 000	21%
nmVOC ^a	195 000	222 000	12%

^a nmVOC is the abbreviation for non-methane volatile organic compounds.

within 2010. About 25 % of the Norwegian emissions of NO_x are related to domestic shipping and 12 % to the fishing fleet [43]. Figure 2 shows the NO_x emissions from the main contributors: Road transportation, the oil and gas industry, and domestic shipping and the fishing fleet are responsible for about 80% of the emissions [44].

Figure 2 shows that from 1990 to 2005 the NO_x emissions from road traffic have decreased, whereas the opposite is the case in the oil and gas industry, and domestic shipping and the fishing fleet. According to White Paper 26 (2006-2007) [42], the emissions from road traffic are decreasing strongly, so efforts have to be put into domestic shipping, the fishing fleet, and parts of the oil and gas industry. Analyses show that the costs of reducing the emissions from domestic shipping and the fishing fleet are moderate compared to efforts in the oil and gas industry [45].

The type and amount of emissions from a fishing vessel vary depending on engine type and power, average utilization of the engine, the fuel system, the intake of air etc. [7]. Table 7 shows the fishing fleet's emissions in 2005. These calculations are based on the method described in [5], derived from fuel costs and fuel prices, and when compared with figures from White Paper 26 (2006-2007) [42], the calculations are consistent.

From the above discussion, the fishing fleet has to reduce its emissions extensively. The question is by how much the fishing fleet should reduce its emissions compared to other sectors. Two scenarios for CO₂ and NO_x can be outlined from this question:

- (1) The total Norwegian CO₂ emission reduction within 2008 should be 6,9 %:
The fishing fleet reduction = 6,9 % or 78 279 tonnes.
- (2) In a socio-economic perspective, some sectors (for example the fishing fleet) should reduce the CO₂ emissions more than other sectors (for example the oil and gas industry), due to costs and efficiency: The fishing fleet reduction > 6,9 %.

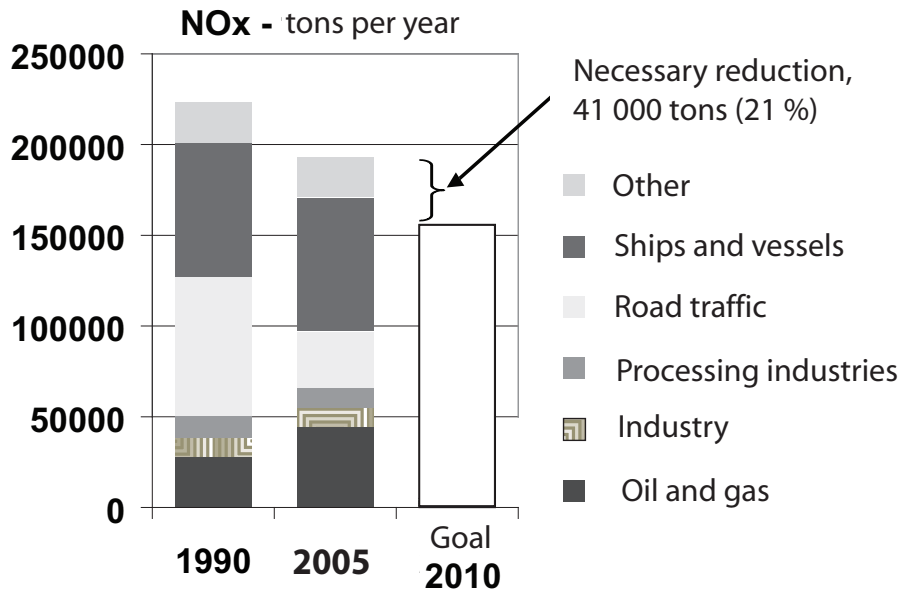


Fig. 2. NO_x emissions, main sectors, 1990-2005 [42, 44]

Table 7

Total emissions and total catch for the fishing fleet, 2005, in tonnes. Based on methods described in [5], with updated information from [32].

Emission type	Tons
CO ₂	1 134 484
NO _x	22 904
SO ₂	1 217
CO	716
PM	286
HC	716

- (1) The total Norwegian NO_x emission reduction within 2010 should be 21 %:
The fishing fleet reduction = 21 % or 4810 tons.
- (2) In a socio-economic perspective, some sectors (for example the fishing fleet) should reduce the NO_x emissions more than other sectors (for example the oil and gas industry), due to costs and efficiency: The fishing fleet reduction > 21 %.

There are different ways to reduce the emissions from fishing vessels, for example by optimizing hull form and the speed, by means of engine technical measures, by

use of waste heat for producing electricity onboard and for cooling, or by changing energy carrier from Marine Gas Oil (MGO) to, for example, Liquefied Natural Gas (LNG). Use of LNG may reduce the CO₂ emissions with approximately 20 % and the NO_x emissions with 85 % [46]. If 40 % of the large ocean-going ring net vessels, 50 % of large coastal vessels, and 50 % of all fresh fish trawlers are converted to LNG, the CO₂ reduction will be about 50 000 tonnes,¹ and the NO_x reduction will be about 4000 tonnes [46], the latter not far from the NO_x criteria in scenario 1. Nevertheless, converting many vessels to LNG operation is not an easy task, illustrating the ambitious level of the Norwegian commitments to the Kyoto and Gothenburg protocols.

4 Discussion and conclusions

This article has proposed criteria that can be used by fisheries management to evaluate the performance level of sustainability in the fishing fleet, and different aspects of such criteria have been discussed. The article has also visualized the importance of iterative evaluations in the systems engineering process.

Establishing acceptance criteria is complicated, because even though they may be based on scientists' recommendations, the political objectives and trade-offs are decisive for the result. It could also be questioned to which extent it is feasible to determine specific acceptance criteria, in line with Aven and Vinnem [21]. Nevertheless, for the attribute "GHG emissions/ acidification", there are already "criteria" available based on the Norwegian commitments to the Kyoto and Gothenburg protocols that the government works hard to fulfill [42]. In most cases, the costs of the efforts and the benefits of implementing them will determine the measures chosen, but the criteria serve as a baseline for making decisions that influence the sustainability of the fishing fleet.

Table 8 sums up the proposed criteria for the attributes. The accident risk criterion uses the 1986 Norwegian official report [20] as a starting point, but reduces the criterion to more than the half of the recommended level at that time. The risk in corresponding industries, such as in the oil and gas sector, has decreased the last 20 years, so government ambitions should be higher than 4-5 fatalities in average; the criteria here being proposed to 3-4 fatal accidents a year.

Regarding the GHG emissions/acidification, it is assumed that fulfilling the commitments to the Kyoto and the Gothenburg protocol means that the Norwegian level of emissions is sustainable, however, it may be questioned if the Kyoto protocol is ambitious enough. The Norwegian government recently stated that the GHG emissions should be reduced with 30 % within 2020 [47]. Then the fishing fleet may

¹ Own calculations based on methods from [5] and input from [32, 41, 46].

Table 8
Summing up the proposed acceptance criteria for the attributes.

Attributes	Acceptance criteria
Accident risk	3-4 fatalities/year (2005 employment)
Employment	Historical level, policy target
Profitability	Historical level, policy target
Quality of the fish meat	Historical level, as low as possible
Catch capacity	Historical level, policy target
GHG emissions/acidification	CO ₂ -Scenario 1: =1.056.205 tonnes
	CO ₂ -Scenario 2: >1.056.205 tonnes
	NO _x - Scenario 1: =18 094 tonnes
	NO _x -Scenario 2: >18 094 tonnes
Bycatch/selection	Historical level, as low as possible

have to reduce the emissions far more than indicated in Scenario 1.

For employment, profitability, quality of the fish meat, catch capacity, and by-catch/selection, it is hard to establish quantitative criteria due to lack of data or dependency on government objectives which are not specific or quantitatively described. Using the past performance level as a reference, it is still possible to assess whether the performance of the fishing fleet is desirable or not.

The criteria in Table 8 may be used to select the solution(s) that, for example, reduce the CO₂ and NO_x emissions according to government objectives. In the systems engineering process, the first step is related to analyses of the need for a sustainable fishing fleet as part of the management objective of achieving sustainability in the fisheries. The attributes reflect the characteristics of a sustainable fishing fleet, which means that the requirements (step 2) can be derived from the attributes. The performance indicators (step 3) specify the requirements and measure the performance of the different system alternatives, which in this case are the different fishing vessel groups.

To determine if one of the system alternatives is more desirable than the others, trade-offs may have to be made (step 4), as some aspects, for example GHG emissions/ acidification, may be considered to be more important than other aspects, such as employment. If the different fishing vessel groups are to be assessed on government objectives to sustainability, acceptance criteria have to be determined, preferable early in the systems engineering process. The sustainability performance

of the attribute GHG emissions/ acidification shows that the fishing vessels do not fulfill the criteria, and action has to be taken to reduce the gap between the measured performance and the desired performance. Action can be related to step 5 of the systems engineering process, which may involve design of LNG operated fishing vessels.

Testing and evaluation (step 6) are used to verify that the new system fulfills the initial requirements and criteria. In the systems engineering process, evaluation is iterative and endures through the whole system development and configuration. Input from the evaluations are used to modify the system design until the final solution is determined. Described shortly, this means that in a systems engineering perspective, the criteria in Table 8 may be used to evaluate different technological solutions that may impact the overall objective of achieving a sustainable fishing fleet. For fisheries management, the criteria may tell when the results from the evaluations that use the performance indicators are “acceptable” or when action is necessary when the performance of the fishing fleet is not sustainable enough. The performance indicators should be measured at regular intervals, as means of evaluating management effectiveness and goal achievement over time.

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Article 7

Improving the environmental performance of the fishing fleet by use of Quality
Function Deployment (QFD)

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Article 8

Risk in fisheries management: From rule-based to function-based management
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RISK IN FISHERIES MANAGEMENT: FROM RULE-BASED TO FUNCTION-BASED MANAGEMENT IN NORWAY?

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ABSTRACT

Great efforts have been made in order to manage the fisheries more sustainably, but so far, most of these efforts have failed. This is putting the welfare of current and future generations at risk. The fishing fleets have catching capacity that well exceeds the rate at which ecosystems can produce fish, and thus many fish stocks are being overexploited.

One of the objectives of the Norwegian government is to manage the fisheries in accordance with sustainable development. Sustainable development and risk management are frameworks with some mutual qualities. In the Norwegian petroleum industry, risk management of Health- Safety and Environment (HSE) is based on functional or goal-oriented regulations. Functional regulations focus on the result without describing in detail how it may be attained, e.g. an acceptable safety level at a petroleum installation.

This paper discusses the possibility of transferring experience and knowledge of risk management and functional regulations from the Norwegian petroleum industry into the Norwegian fisheries management in order to increase sustainability in the fishing fleet. An important research question is the connection between an acceptable sustainability level in the fisheries, and transforming the fisheries regulations into functional regulations based on management objectives.

Keywords: Sustainable fisheries, risk management, functional legal regulations

INTRODUCTION

In a global perspective, the overcapacity in the fishing fleets is considered as the most important reason for overexploitation of the world's resources. Both globally and nationally, overcapacity leads to misuse of the production resources in the society. Thus, capacity adjustment is necessary to obtain a sustainable exploitation of the marine resources. Capacity adjustments have been and still are an important challenge in the Norwegian and international fisheries politics [1].

Most of the Norwegian regulations have been introduced as a consequence of resource- and capacity problems. Despite the efforts of limiting an additional expansion of the fisheries, the catch capacity has continued to increase. Standal [2] has found that even though the number of vessels has been reduced within a regulated regime, factors like new gear technology, larger boats, more engine power etc. have contributed to more effective fishing vessels. In order to reduce overcapacity, various policy instruments have been introduced over time in the different fleet groups. Voluntary structural means have been carried out to adjust the capacity, but the challenge is to make sure that these instruments have the intended effect.

A small quota foundation for the fishing fleet leads to low profitability, which again reduces the ability for renewal in the fleet. Old vessels may reduce the fleets' ability to compete for qualified employees; they reduce the safety, the catch effectiveness, and the quality of the fish meat. Another consequence of overcapacity is complex and detailed regulations, with high inspection and administrative costs [1].

The past decades have been a difficult period of adjustment for the Norwegian fisheries management. The early Norwegian regulations were based on the use of licenses, but were later on expanded to total quotas, group quotas, and individual vessel quotas. Broadly speaking, all kinds of regulations have been tried; limitations to number of boats, licenses, size of vessels, type of fishing gears, replacement regulations, etc. [3]. The problem is that the fishers compensate for the regulations by a process called technological creep. This means that the fishers adapt their gear, vessels and behavior to maximize profit when effort restrictions are imposed, a process that leads to little reduction of catch effectiveness [4]. Today, the Norwegian regulations are mainly aimed at controlling catch capacity by use of licenses and vessel parameters, at controlling resource exploitation by use of quotas, by limiting access, by restricting gears, and by allocating resources between vessel groups, gear groups, regions, and with regard to the delivery situation in the fishing industry [5].

The regulations imposed, have been based on a mutual understanding between the authorities and the fishers' own organizations. Nevertheless, the regulatory system has been much criticized. One of the main problems is that the system is complicated, difficult to follow, cost-driving, and very detailed [3], [5], [6], [7]. In 2003-2004 the goal achievement in fisheries management was evaluated by the Office of the Auditor General. The report concluded, among other things, that the Ministry of Fisheries and Coastal Affairs has only to a very limited extent carried out systematic analyses of the effectiveness of regulations and various arrangements [8].

The problem of overcapacity necessitates consideration of technology as a dynamic process in the fisheries. The discussions of systems engineering principles in fisheries management integrate the technological dimension with the prevailing scientific disciplines of biology, economy and social sciences [9], [10]. In systems engineering the whole is more than just the sum of its parts, which in most cases implies a top-down perspective of the system.

The objective of this paper is to discuss new approaches to regulations of the fishing fleets that may simplify and improve the current regime, by applying a top-down perspective. Simplification of the public regulations in the business sector is on the Norwegian government's agenda through the plan of action "Simplifying Norway" (In Norwegian: "Et enklere Norge") [11]. The discussion in this article brings in experiences from the functional legal requirements within health, safety, and environment (HSE) systems in the Norwegian petroleum industry, where the detailed regulations have been replaced by functionally oriented requirements. This article concludes that a technological perspective on rule development in the fishing fleet through the systems engineering perspective, especially on those rules affecting the technological development, may lead to increased sustainability and reduced complexity in fisheries management.

MANAGEMENT OF THE NORWEGIAN FISH RESOURCES

The Norwegian public regulations regarding the fisheries are divided into three phases: Admission to catch fish, the fishing itself, and landing of fish. The regulations are complex and there are comprehensive demands to reporting. The complexity has increased due to the closing of the commons, introduction of technical regulations, quota and control systems. Problems related to complicated regulations are well documented [5], [7], [12]. Simplification and harmonization is an ongoing process with high priority in fisheries management [6].

The fishers' main criticism of the regulations is that the set of rules is so complex that it is difficult to understand the content of the rules, and to know which rule applies at what time. Thus, violation of the rules may occur without intention [7]. A simpler set of rules for fisheries management is considered to be a prerequisite for industrial and commercial development by removal of obstacles to such development,

without sacrificing a responsible management of the resources. Parts of the regulations are already examined, and the work continues [1].

In Norway “paragraph vessels” is a remark which is used partly to describe obstacles to the fishers' effective adaptation in the fisheries, and partly to express an effective policy instrument preventing unprofitable overcapacity in the fishing fleet. Since the 1970's, the number of “paragraph vessels” in the Norwegian fisheries has increased as a result of the technological development. The fisheries management has put limitations to physical parameters of the vessels, such as length and gross tonnage weight, in order to adjust the catch capacity to the available resources.

The regulations concerning the “paragraph vessels” generate considerable side effects. The fishers, ship owners, and consulting engineers use their creativity to adapt the design of the vessels and evade the law. Besides, many fishers have quota rights in different fisheries, and thus try to design the fishing vessel for dual operation. Investors seek to maximize catch capacity. These various priorities have caused the development of “paragraph vessels” with a negative impact on the stability of the vessels, on the working environment for the fishers, on profitability, and on fuel consumption [13].

The formal procedures and politics in fisheries management is further described, e.g., in [7], [14].

A SYSTEMS APPROACH TO MANAGEMENT OF THE NORWEGIAN FISH RESOURCES

The ecosystem approach has been agreed on as a management principle by the Norwegian parliament [15]. The framework for the ecosystem approach, that the Ministers at the 5th North Sea Conference in Bergen in 2002 agreed on, has 5 components [16]:

- Objectives or targets based on the overall condition of the ecosystem
- Monitoring and research, necessary to provide relevant information about the status and development of the ecosystem
- Assessment of the current situation in the ecosystem
- Advice to be used in the decision-making
- Adaptive management, which means that measures are adapted to the current situation in the ecosystem in order to achieve the stated objectives

The marine fisheries are complex adaptive ecosystems, difficult to understand completely and even harder to control. An ecosystem-based management of the marine resources recognizes that nature is integrated, and it promotes decision-making in a holistic perspective.

In a system theory perspective, a core concept is “wholeness”, which means that a system is not understandable by evaluation of the constitutive parts in isolation [17]. The Norwegian fisheries regulations constitute a complex system that has evolved in a time period of major technological developments. Since the technological development in the fisheries is an ongoing, dynamic, and continuous process, the solutions that yesterday were considered to be up-to-date, may already tomorrow be out-of-date. It is impossible for the authorities to be ahead of the development, which may imply that the regulations should not be too detailed [18]. Still, the existing regulations have been imposed as a result of a stepwise development and a crisis-driven process, so that the system today is constituted by several individual decisions instead of a planned whole where implemented efforts are adapted to each other [7].

Holistic problem-solving may characterize the systems engineering process, which starts by identifying the user or the stakeholders' needs. There are several stakeholders of varying relevance to the fisheries,

e.g., the fishers, the management, the society etc. Stakeholders and their relation to fisheries management in a systems engineering perspective, is further discussed in [9]. Based on the needs of the stakeholders, the requirements to the system may be determined and specified, conflicting objectives may be traded-off, and the chosen solution may be designed, tested, and verified [19]. The objectives of the various regulations in the fisheries may be related to requirements and specifications to the fisheries system performances. The top-down approach of the systems engineering process, should not be confused with the characteristic of a centralized, top-down management in the fisheries.

Systems engineering may be used to integrate a technological perspective into fisheries management. Further discussions of the systems engineering process related to fisheries management may be found in [9], [10].

SUSTAINABLE DEVELOPMENT AND RISK MANAGEMENT IN THE FISHERIES

Sustainability and risk may be seen as complementary concepts for studying and managing environmental consequences of human actions [20]. Both concepts are much discussed, still the most authoritative definition of sustainable development may be that of the Brundtland commission's: "Development that meets the need of the present without compromising the ability of future generations to meet their own needs" [21]. "Risk" may be described as the potential that a physical loss will occur, where uncertainties are integrated in the measurement of risk. Mainly, risk management deals with risk in terms of the probability of given undesirable outcomes [20].

Table I: A comparison between risk management and sustainable development, based on [20].

Feature	Risk	Sustainability
Main focus	Loss	Benefits and system limits
Type of potential loss considered	Mainly human/biological/physical	Environmental, economic, social
Uncertainties	Explicitly calculated	Implicit
Level of analysis of potential loss	Individuals/groups	To systems
Time reference	Short to medium-term future	Medium- to long-term future
Feature	Risk management	Sustainable development
Decision-making approach	Risk-benefit assessment/optimization	The Precautionary principle
Context	Management	Development (change)

Increased added value in the marine sector is an overall objective in Norwegian fisheries politics. In order to achieve this goal, the fish resources have to be managed in a sustainable way [1]. Sustainable development in the fisheries means to establish a system that fulfills the needs for fish both for present and future generations. Such a system should prevent hazards that may threaten the sustainability. Risk management is a tool that may be used to measure and reduce potential hazards [22]. Table I sums up the similarities and differences between risk management and sustainable development, based on [20].

FUNCTIONAL RULES, PRESCRIPTIVE RULES, INTERNAL CONTROL, AND THE TOP-DOWN APPROACH

The current trend in development of rule systems is to move from detailed prescriptive rule solutions towards functional rule solutions directed at decision-making and management [23], [24]. A goal-oriented or functional rule states what the legislator means the result should be, e.g., “a fully responsible working environment”, without specifying how the result is to be achieved. This implies an increased use of internal control principles that represent more hierarchical strategies to rule system development. Functional rules require frequent evaluations of performance, which may be carried out by use of performance indicators. The focus of such rules may be directed towards technical equipment, human performance, and organizational conditions [23].

Internal control as the main principle for controlling safety was first introduced in the Norwegian offshore petroleum activities in the 1980's. The reform was made mandatory for all private and public enterprises by new regulations in 1992 [25]. At the same time, the internal control was extended from major hazard control and occupational safety to promote improvements in the working environment and safety in enterprises, prevent damages to health or disturbances to the environment from products or consumer services, protect the external environment against pollution, and improve treatment of waste [26].

The Norwegian Internal control regulations define internal control as “Systematic measures designed to ensure that the activities of the enterprise are planned, organized, performed and maintained in conformity with requirements laid down in or pursuant to the health, environmental and safety legislation”. Compared to a control regime of detailed regulations, the internal control regulations focus on the obligations of the responsible person of the enterprise, on systematic and documented actions based on principles for written HSE objectives, on system deviation control, and on system audits as a control tool for the enterprise and for the authorities [25].

Various types of regulation regimes have advantages and disadvantages depending on the content of the rule and the stakeholders involved. Functional regulations presuppose that the rule-imposer knows what the desired goals are and that the rule-follower knows how to achieve those goals. Functional regulations combined with clear specifications of responsibility, may contribute to fulfillment of the rule objectives. Complexity, technological development, and rapid adjustments may complicate updating of the regulations. Thus, functional regulations handle rapid development better than detailed regulations, because the focus is on the legislative objectives, and not on the instruments [23], [27]. Functional based requirements presuppose detailed knowledge about the requirements to the system and how the system is supposed to function. This may be related to the functional analysis, which is the process of translating system requirements into detailed design criteria, in the systems engineering process [19].

Every system is made of components, and every component can be broken into smaller components, in a hierarchical structure. The total system, at whatever level in the hierarchy, consists of all components, attributes, and relationships needed to achieve an objective. The systems engineering process is based on a top-down approach (deductive), however, most projects will first reduce the complexity by reducing the system into its elements, and then bottom-up design (inductive) to realize the elements for that system [28]. In rule development, this implies that prescriptive or detailed rules should be derived from higher order goal-oriented rules. According to Hovden [25], internal control means both a top-down approach and a bottom-up approach, represented by the top management and democratic stakeholder participation.

A functional set of rules will obviously be of smaller format than more detailed regulations. Still, general requirements should be avoided, because generalization makes the regulations more difficult to understand so that instructions may be needed instead. If many instructions are needed, the total amount of regulations may be large and too complex. Inspections and control under conditions of functional

regulations require a high level of competence and knowledge, and may also face challenges related to clarification of the content in the regulations. Very general regulations may cause problems for the police and law courts, as rule violations are difficult to determine so that equality before the law may be undermined.

Detailed or prescriptive rules describe how to respond in certain situations. The disadvantage with detailed regulations is that the rules may be complex, fragmented, and that they may slow down the progress in regulated areas. The ambition level may also be lower than the potential in the industry. Detailed regulations require a continuous update in order to follow the developments [27].

FUNCTION-BASED MANAGEMENT IN THE NORWEGIAN OFFSHORE PETROLEUM INDUSTRY

When the offshore petroleum industry in Norway started, in the mid 1960s and early 1970s, the safety equipment and emergency response systems had to be regulated. At that time, the Norwegian Petroleum Directorate made detailed prescriptive regulations, similar to those commonly used in shipping. Gradually, it became apparent that another approach was necessary if further safety improvements were to be achieved, and the detailed regulations were replaced by functionally oriented requirements. The new requirements encourage extensive use of analysis and risk-based approaches, and an increased flexibility in the choice of solutions. The changes were implemented to achieve focus on accident prevention instead of protection, but also to benefit from improvement processes in a modern industry dedicated to “management by objectives” [29].

The Norwegian internal control reform was an attempt to develop new approaches and means to handle problems and misfits between technology development and regulations in the offshore petroleum industry in the 1970's [25]. In order to match regulatory risk problems and means, the Norwegian Petroleum Directorate (NPD) decided that the operating companies on the Norwegian continental shelf should take responsibility to design the most appropriate solutions. The reason for this was to ensure the safety of each single activity, based on risk and emergency preparedness analyses. The success of such a decision presupposes dedicated and sincere companies that really wish to improve safety. Unfortunately some companies have misused their increased freedom to cut “needless” and costly emergency response resources [29].

In 2001 it was decided to include all relevant requirements from the pollution and health authorities into one set of health, safety, and environment (HSE) regulations for petroleum activities. From 1990-1993, all previous regulations were replaced by 14 new regulations, which proved to have common organizational and management components, operational and maintenance requirements, and general safety principles, such as barrier requirements. In 2001, four groups were developed, and the common requirements became four new regulations:

- Duty of information regulations. Requirements related to the information to be submitted to the authorities
- Management regulations. Requirements related to health, safety and environment management systems
- Facility regulations. Requirements related to design and outfitting of facilities
- Activity regulations. Requirements related to the conduct of activities

The companies operating on the Norwegian continental shelf have obtained their licenses on the basis of mutual trust; a section about safety culture is included in the new regulations in order to emphasize management commitments to safety.

FUNCTION-BASED MANAGEMENT IN THE NORWEGIAN FISHERIES

Sustainable development and risk management have common characteristics. The trend in risk management is a change from detailed prescriptive regulations towards goal-oriented functional regulations. The HSE regulations in Norway have forced the companies operating on the Norwegian continental shelf to participate proactively in the process of increasing the safety level. Ecosystem-based management in the fisheries recognizes the need for a holistic decision-making, which implies more long-term planning in the fisheries. The overcapacity in the fisheries is a major problem that has to be reduced in order to increase the sustainability level in the fisheries. The technological development and the problem of overcapacity indicate that use of goal-oriented or functional regulations may be applicable in the Norwegian fisheries management, not only as means to increase, e.g., safety^a, but as means to increase the overall sustainability in the fisheries.

One attribute of a sustainable fishing fleet is fuel consumption or the amount of greenhouse gasses emitted [30]. Fuel consumption is an important attribute in a technological perspective of sustainability [10]. Despite the Norwegian regulations restricting the technical fishing vessel parameters, and a substantial reduction in the total number of fishing vessels in the time period 1980-2004, the total engine power (hp) in the fishing fleets has increased [31] (Figure 1 and 2). Engine size may be considered as an important characteristic of a fishing vessel’s catch capacity [2].

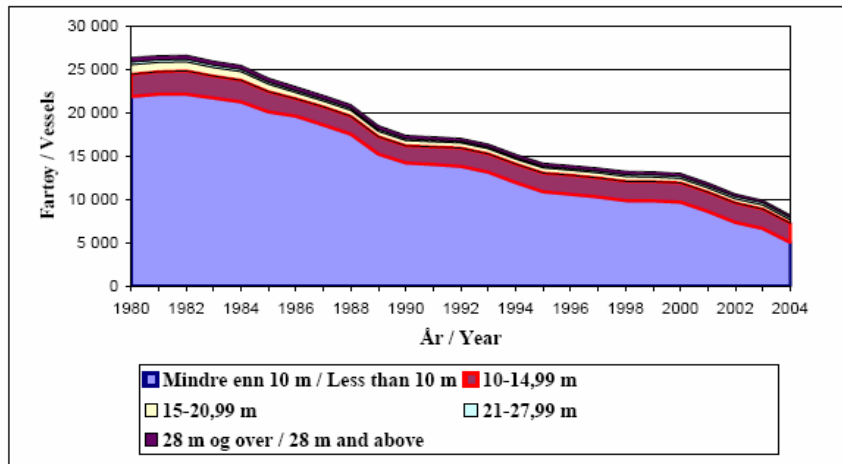


Figure 1: NUMBER of fishing vessels by length group. 1980-2004 [32].

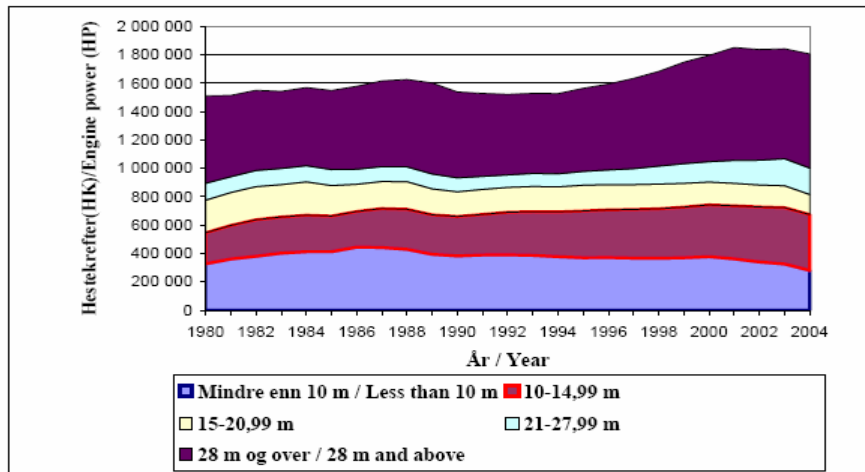


Figure 2: TOTAL engine power (hp) by length groups. 1980-2004 [32].

Reduction of greenhouse gas emissions from the fishing fleet is on the agenda of the Norwegian government as Norway is committed to international agreements such as the Gothenburg protocol [33]. Also, some vessel groups, e.g., the shrimp trawlers, experience serious profitability problems due to the increasing fuel prices [10]. Thus, a suitable question is if the technical vessel parameter restrictions and the Norwegian system of vessel quotas, that put limitations to the design of fishing vessels, should be replaced by regulations that are aimed at reducing the energy consumption.

In 2001, the Ministry of Fisheries proposed free green-house gas emission quotas for the fishing fleet [34]. The quotas are suggested to be estimated and allocated based on the fuel consumption of the most effective vessels in each vessel group. This means that most vessels will be assigned too small quotas, so that they have to pay for excess emissions. The proposition would probably lead to increased taxes for the fleets, which today are exempted from CO₂ tax. Such a system is a very interesting issue, because it may encourage use of less energy intensive catching methods.

A system of emission quotas would most likely have to be based on the vessels reported consumption of fuel. A goal-oriented regulation regime requires a system for internal control, which means that the vessel owners have to document their solutions to the objectives in the regulations, e.g., how they comply with their emission quota. Internal control means that written documentation has to be available for inspections, which may be carried out regularly or on grounds of suspicion.

Such documentation could be related to the design of the vessel. When fishing vessels are admitted to the fisheries, an overall objective should be to construct the vessel with the aim at achieving the lowest possible consumption of fuel. The ship owner would then have to document that the vessel is fitted with the most suitable equipment and fishing gear, that the vessel is as safe as possible, and that the fuel consumption is as low as possible. In order for such regulations to be effective, there must exist penalties and other sanctions for those not complying with the rules.

Use of energy or emission quotas as a replacement for limitations to technological vessel parameters or the vessel quota system could be considered as an attempt to introduce more functional legal regulations in the fisheries. The fishers would have to decide for themselves how to catch the most fish with as little fuel as possible, and the technological development could possibly be moved towards an increased focus of achieving sustainable solutions.

DISCUSSION

Several efforts have been made in order to manage the fisheries more sustainably, but few if any attempts have succeed, as overexploitation and overcapacity in the fishing fleets still are huge problems. The main focus of fisheries management is on biological estimation methods and assessments, and on economic profitability. Overcapacity may be related to the continuous process of improving vessels and catching gear technology, which indicates that the technological dimension should be further integrated into fisheries management.

Fisheries management is a huge and complex area, struggling with many stakeholders promoting conflicting objectives. In Norway, the imposed fisheries regulations have been ad hoc solutions to problems when they have occurred. Thus, the regulations have become very complicated. Simplification of public regulations is on the agenda in Norway, including the fisheries. Projects have tried to reduce the complexity in the regulations [6], [12], [35], of which a few have used a goal-oriented approach to propose more user-friendly HSE-regulations within the fish industry [36].

A political goal in Norway is to maintain a diversified fishing fleet structure [3], [35]. The Limited Entry Act has structural effects, because certain conditions have to be fulfilled in order to gain access to

participation in a fishery. Quotas are allocated between the different vessel groups. Abandoning or changing the restrictions to the technical vessel parameters and the system of vessel quotas, are controversial issues, because they affect fishery politics. Still, if Norway is to comply with international agreements such as the Gothenburg protocol, efforts of reducing the green-house gas emissions from the fishing fleets have to be implemented. The increasing fuel prices also cause problems of reduced profitability in some fisheries, which indicates that the fuel consumption should be lowered.

Internal control related to the operation of the fishing vessels, requires documentation of how the ship owners comply with the rules. The existing regulations demand several documents to be completed in order to gain admission to the fisheries. Internal control documentation should therefore be a replacement for some of the existing requirements to documentations, and not as an addition to existing regulations.

The question raised is very complex, and there are no final conclusions. Even though functional legal regulations have worked for risk management in the Norwegian offshore petroleum industry (even though the subject has been and is thoroughly debated), the fisheries is a sector with different characteristics and challenges than those of the petroleum sector. Also, risk management and sustainable development have differences. Blakstad [23] concludes in her Ph.D. dissertation, about adaptation of rules in the Norwegian railway system towards a more risk based approach and a modernization of existing rules [23], that the modification process abandoned the intentions of hierarchical and risk-based approaches. The main reason was that the new approaches did not sufficiently integrate existing railway knowledge, found to be important for the safety performance, into a new risk-based approach system. Existing knowledge and prescriptive rules were used as a foundation in the safety work.

Drangeid [29] concludes that if the new regulations were made more detailed and prescriptive again, the safety level in the petroleum industry would hardly lead to improved hazard management. Hovden [25] argues that the Norwegian system of internal control, especially of that applied in the offshore oil industry, has been regarded as a model for other industries to follow. However, this reputation was deserved in the eighties, but in the nineties safety was increasingly sacrificed due to cost cutting. Safety depends more on the political and economic context than it does on the technicalities of the regulatory regime.

The discussion in this paper is based on the idea that a systems engineering perspective on rule development in the fisheries, with a holistic approach to problem solving, especially on those rules affecting the technological development in the fishing fleet, may lead to increased sustainability and reduced complexity in fisheries management. Functional or goal-oriented rules may be considered as means to integrate a more holistic management system, as risk management and sustainable development have common characteristics. Thus, such approaches to regulations and management may be applicable to discuss and evaluate. The discussion here is by no means a conclusion on how the management regulation system should be transformed. Risk management and measurement of the current risk level at a petroleum installation, is a more concrete task to do than measurement of the level of sustainability in the fishing fleet. Still, reducing complexity in the fisheries management requires a holistic perspective in the decision-making and problem solving.

FURTHER WORK

The issues raised in this paper should be further explored and related to practical implementation. The consequences of a transformation to more use of functional regulations in fisheries management should also be thoroughly evaluated.

ACKNOWLEDGEMENT

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ENDNOTES

^a Safety may also be considered as an important attribute of a sustainable fishing fleet [11].

Article 9

System performance evaluation of the Norwegian cod-fishing fleet

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SYSTEM PERFORMANCE EVALUATION OF SUSTAINABILITY IN THE NORWEGIAN COD-FISHING FLEET

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ABSTRACT

The objective of this paper is to discuss systems engineering principles in the assessment of sustainability of the vessel groups that are fishing cod in northern Norway. An important part of the systems engineering process is specification of system performance. Thus acceptance criteria for the performance of the fishing fleets are investigated, as well as use of performance indicators, and sustainability attributes. The results show, among other factors, that the energy consumption is higher in the Norwegian ocean-going fleet than in the coastal fleet, whereas the opposite is the case for the number of fatalities from accidents at work.

1. INTRODUCTION

Globally, overcapacity is considered as the most serious threat to sustainable fisheries. The problem of overcapacity indicates the need for a stronger integration of technological aspects into fisheries management (Standal, 2005). Technical and social systems increase in their complexity and vulnerability, and human-made systems, such as the fisheries, are not in conformance with natural systems. Technology should work with natural systems, not against them. Systems engineering is a process that may facilitate a technological, holistic, and interdisciplinary perspective in fisheries management (Utne, 2006).

Systems engineering deals with analysis and design, operation, and maintenance of large integrated systems in a total life cycle perspective. Technology, management, legal aspects, environmental and social issues, finances and corporate strategies are taken care of by total system integration. The systems engineering process is iterative, and expands on the common sense strategy of understanding a problem before solving it, examining alternative solutions, and verifying that the chosen solution is correct before implementing it. Use of the systems engineering process in fisheries management may give increased visibility and a reduction of the risks associated with the decision-making process. In (Utne, 2006), the systems engineering process related to fisheries management is further elaborated.

The objective of this paper is to discuss systems engineering principles in the assessment of sustainability in the cod-fishing vessel groups in northern Norway. The first part of the paper discusses the concept of sustainability in the fishing fleet as well as acceptance criteria and use of performance indicators. The second part evaluates sustainability based on six attributes in five vessel groups.

2. SUSTAINABILITY IN THE FISHING FLEET

Sustainable use of renewable resources is the main objective of the Norwegian fisheries management (The Norwegian Ministry of Foreign Affairs, 2002). Since "Our Common Future" (World Commission on Environment and Development (WCED), 1987) was published, several definitions and interpretations linked to the concepts of sustainability and sustainable development

have been proposed, with sometimes conflicting views that cause difficulties in achieving sustainable use of resources (Rosenberg, 1993). Sustainability cannot be investigated within the limits of a single scientific discipline, because it may involve ecology, engineering, law, sociology, economy, physics, and politics. This multi-disciplinarity introduces cross disciplinary communication problems which causes conceptual difficulties and unclear measures of sustainability. Thus, the concept of sustainable fisheries has to be clarified, and systems engineering may be a suitable process for handling sustainability issues (Utne, 2006).

The scientific disciplines may be reflected in the three dimensions of sustainable development: The social, environmental, and economic dimensions. The environmental dimension involves exploitation of the fisheries with a long-term perspective in mind, which means that future generations also must be able to fulfil their needs for fish. Fishing contributes to human welfare by fulfilling needs for employment and income, cultural needs and recreation (Food and Agricultural Organization of the United Nations (FAO), 1999). These aspects are captured in the social dimension of sustainability, which also includes human rights, moral and justice (Van Dieren, 1995). The fisheries politics should be based on democratic principles, such as stakeholder inclusion and distribution of power (Album, 2001). Safety is another important aspect of the social dimension of sustainability, because accidents cause grief, stress and loss of social security. Statistics of the fisheries show that the profession is one of the most dangerous in Norway as well as in many other countries. The high accident risk affects new recruitment, as young people may have other expectations and demands than the old fishers. The high accident rate is also an economic problem; skilled employees disappear, and insurance costs are high (Aasjord, 2005). The economic dimension of sustainable fisheries is related to maintenance of human-made capital. This may involve the controversial concept of sustainable growth. Damage caused by the catching process and the handling of the fish onboard the vessels, influences the quality of the fish meat. Such damage reduces the prices paid for the fish and causes income loss (Gregersen, 2005).

2.1 Attributes of sustainable fisheries in Norway

Based on the former discussion, there are several attributes that may be used to describe sustainability in the fishing fleet, depending on how the system boundaries are defined. The main problem addressed in this paper is related to overcapacity; thus the system boundaries are limited to the fishing fleet and the vessels in their operational phase. This means that the marine ecosystem, wherein the fishing vessels are interacting, is outside the system boundaries. Based on the former discussion of sustainable fisheries, the selected attributes of a fishing fleet are shown in Figure 1.

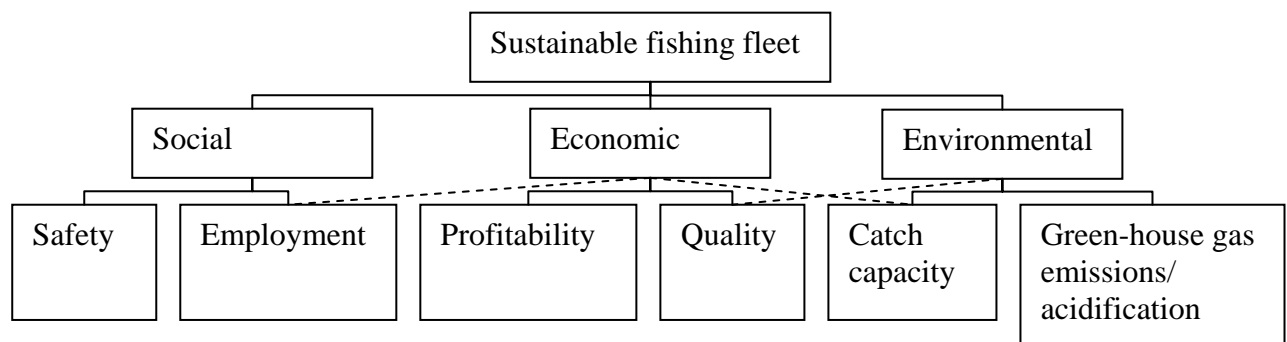


Figure 1: Dimensions and attributes of sustainability in the Norwegian fishing fleet. The dashed lines indicate that the division is not absolute.

3. SYSTEM PERFORMANCE EVALUATION OF SUSTAINABILITY

Frequent evaluations of the performance of the fishing fleets over time may show a positive or negative development with respect to sustainability. Use of performance indicators (I) in the

Norwegian fisheries, and monitoring them at certain time intervals, would enable fisheries management to find out if the development of the fisheries is brought near the objectives. The performance indicators are means of evaluating the fisheries management in a systems perspective. A general discussion of performance indicators related to systems engineering may be found in (Utne, 2006).

To interpret changes in the performance indicators, reference values or acceptance criteria should be determined. The reference levels may be established by considering past performance of the system or from using mathematical models that indicate how the system should be expected to perform (Food and Agricultural Organization of the United Nations (FAO), 1999). Acceptance criteria are commonly used in, e.g., risk management to express the tolerable risk level in a specific time period or of an activity.

Acceptance criteria are often related to specific quantitative upper or lower boundary, even though there may be large uncertainties attached to these estimates. Qualitative interpretations are often easier to understand, but they may be more difficult to assess. Thus the best acceptance criteria may be both qualitative and quantitative (Solli, 2002). An acceptance criterion related to a sustainable catch capacity level in the fishing fleet, may be difficult to define. The overcapacity in the fishing fleet is both environmentally and economic unsound. Methods of capacity assessment or measurement of utilization of capacity may be based on technical capacity characteristics and economic calculations (Ward, 2004).

Paid prices per kg fish or income loss due to reduced quality may indicate the quality of the fish when delivered onshore. The accident risk potential may, e.g., be measured as Fatal Accident Rate (FAR), Potential Loss of Life (PLL) or by using risk matrices¹ (Norwegian Technology Centre, 2001). An acceptance criterion for no. of employees may be established using the current level as a reference level, if the management objective is to maintain the current level of employment. For green-house gas emissions/acidification, commitments to international agreements, e.g., the Gothenburg protocol, and the government's environmental strategies may be used to establish criteria (Norwegian Pollution Authority, 2006). Establishment of acceptance criteria is complicated, because even though they may be based on scientists' recommendations, the political objectives and trade-offs are decisive.

The ocean off the northern coast of Norway holds some of the most abundant fish resources in the world, e.g., the cod fishery which is the most valuable Norwegian fishery with 39% of the total catch value of all fish species (Statistics Norway, 2006). The fleet fishing for cod comprises different types of vessels of various sizes, gears, and ways of handling the fish. In 2006, the Norwegian part of the TAC for the cod fisheries north of 62°N is 212 700 tons (The Directorate of the Fisheries, 2006).

In this paper, the vessels are classified according to the following categories² (l denotes vessel length):

- A: Small coastal vessels (net, hand line, Danish seine, long-lining), $l < 15$ m
- B: Medium coastal vessels (except trawlers), $l = 15-27,9$ m
- C: Large conventional vessels (long-lining), $l > 28$ m
- D: Factory trawlers, possibly combined with shrimp trawling
- E: Cod trawlers, possibly combined with shrimp trawling

¹ FAR and PLL are quantitative scales used, e.g., when assessing risk at petroleum installations. Risk matrix is a semi-quantitative method which evaluates different risk scenarios and potential outcomes in a systematic way.

² These categories are in accordance with the vessel groups in the cod fisheries in the statistics made by the Directorate of the fisheries in Norway from 2003 and onwards.

The fishing fleets, A, B, C, D, and E are compared with respect to the sustainability attributes and performance indicators that have been identified.

3.1 Green-house gas emissions/acidification: I_1 = Fuel kg/ kg fish

There are huge differences in energy consumption for the fishing vessels, due to great variances in distance to the fishing grounds, bad weather, wave height, low temperatures and icing, type of catching gears, and conservation of the catch. In a project carried out by Sintef Fisheries and Aquaculture (Ellingsen, 2005), the energy use from 1980-2002 was estimated for different vessel types, as there are no official statements of the exact energy consumption in the fisheries fleet. The calculations in this paper are based on the same methods; by use of financial statements from the Directorate of the Fisheries (The Directorate of the Fisheries, 2002-2004), and information on fuel prices from Statoil, The Norwegian Petroleum Industry Association, Bunker Oil, and Norwegian Customs. Using fuel costs and fuel prices, and by knowing the density of Marine Gas Oil (MGO), the average fuel consumption for each vessel can be estimated. The total consumption of fuel for the vessel groups were calculated by multiplying average use per vessel by the total number of year-round operated vessels in each group.

Table 1: Average fuel consumption kg/kg fish for the vessel groups, 2003 and 2004

Fleet	Fuel kg/kg fish	
	2003	2004
A	0,17	0,15
B	0,18	0,15
C	0,38	0,32
D	0,57	0,47
E	0,57	0,47

Table 1 shows the average fuel consumption per kg fish (round) for the vessel groups calculated in this paper. The smallest vessels have the lowest fuel consumption; however, it is important to notice that the small vessels have shorter distance to the fishing grounds and limited operational season.

3.2 Profitability: I_2 = Earning capacity NOK /kg fish

Profitability and added value are important objectives in the allocation process of the fish resources. In Table 2 average vessel earning capacity per kg fish catch for the vessel groups in 2003 and 2004 have been calculated. The smallest conventional vessels have the highest score.

Table 2: Average vessel earning capacity per kg fish catch, 2003-2004, Based on data from the Directorate of the Fisheries (2002-2004).

Fleet	Earning capacity NOK/kg fish	
	2003	2004
A	4,03	4,56
B	3,15	3,39
C	2,21	3,59
D	1,34	2,25
E	1,28	2,82

In the fisheries, the scarcity factor is access to the fish resources, whereas the capital and labour are open to market prices. Trondsen and Vassdal (Trondsen, 2005) conclude that the smallest vessels have a higher added value per kg catch than the largest vessels, independent of type of fishery, most likely due to lesser capital costs and operating costs, shorter operating time, and probably better utilization of bycatch. Still, the added value per man-labour year is higher for the largest vessels.

The reason may be that the government compensate lower added value per kg catch by allocating larger quotas to the large ocean vessels.

3.3 Employment: I_3 = Average no. of man-labour years/vessel

In Table 3, the number of employees and average man-labour years for 2004 are presented.

Table 3: Number of employees and average man-labour years, 2004 (The Directorate of the Fisheries, 2002-2004).

Fleet	No. of vessels	Total no. of employees	Average man-labour years/vessel	Average no. of working hours/ man-labour year
A	1 111	1788	1,6	2020
B	231	903	3,8	2430
C	38	969	12,8	4480
D	15	782	27,6	3362
E	31	775	14,3	3889

In all, the smallest vessels employ more people than the largest vessels, but there are more man-labour years at the largest vessels. The average numbers of working hours per man-labour year reflect that the ocean fleet uses relief crew, while one man-labour year in the coastal fleet represents one employee (The Directorate of the Fisheries, 2002-2004).

3.4 Accident risk: I_4 = FAR

The total number of accidents in the Norwegian fisheries in the time period 1998-2003 was 1949, of which 61 fatal and 1888 personal injuries (Aasjord, 2005). Table 4 shows the FAR value for the vessel groups calculated in this article.

Table 4: Risk for the vessel groups, 1998-2003 (Aasjord, 2005), (Aasjord, 1998-2003)

Fleet	FAR
A	152
B	35
C	13
D	12
E	19

The FAR value represents the expected number of fatalities per 10^8 hour of exposure³. In the fisheries, the number of man-labour year varies with different vessel groups from one year to another. The FAR values presented in Table 4 are based on the numbers of man-labour years from 2003, as the statistics of the vessel groups from the Directorate of the Fisheries have been changed from 2002 to 2003, making comparison difficult. Thus some uncertainty is introduced, as the average man-labour year in the period 1998-2003 may be slightly different from the year 2003, which is used here. Another uncertainty factor is that the man-labour year numbers only include whole-year operated vessels, which may affect the smallest fishing vessels (Aasjord, 2005). Table 4 shows that the FAR value is highest for the vessel group A.

3.5 Catch capacity: I_5 = Catch capacity

The trawlers have obviously much higher catch capacity than the smaller conventional vessels. In 2004, the average length of a factory trawler (D) was 61,4 m and the average age was 16 years. For the cod trawlers (E) the average length was 51 m and average age was 18 years. For the

³ In the statistics from the Norwegian Labour Inspection Authority the risk of occupational accidents for different industries are presented as number of deaths per 100 000 employees. If these work 1000 hours a year, the number 10^8 is obtained.

conventional vessels (A) participating in the cod fisheries, the average length was about 11 m and average age was 21 years. Other capacity parameters, such as the gross tonnage weight, differ from 13 in average for the smallest vessels to 740 in average for the factory trawlers (The Directorate of the Fisheries, 2002-2004). The increased capacity development in the Norwegian fisheries fleets has been thoroughly discussed by Standal (Standal, 2005).

3.6 Quality: I₆= Quality. Income loss due to reduced quality, NOK

In 2003, about 8 million kg of fish were brought onshore with serious damage. The damage deteriorates the quality of the fish products, and even though the fish-processing industry may reduce the price for the poor quality fish, this was done to only 1,9 million kg cod (Gregersen, 2005). The fishing gear has a great impact on the amount of damaged fish. Also, large catches impact the quality of the fish due to slower intake of the fishing gear, and thus increased standing time, increased pull-in forces which lead to increased pressure on the fish in the hauling equipment, more work, delays, etc. (Karlsen, 2001). A study carried out by the Norwegian Institute of Fisheries Research shows that the highest frequency of quality defects caused by the fishing operation, was found on cod caught by net, and the lowest on cod caught by hand-line (Akse, 2004).

The coastal fleet normally delivers fresher fish than the ocean fleet. The landed value for large cod ($w > 2,5$ kg) caught by the coastal fleet in Finnmark is in general lower than the average prices paid for large cod caught by trawlers. The reasons may be that the quality is better (e.g., than for cod caught by net), or that the grading from the trawlers are better suited the fish processing industry. For the smaller cod, the price differences are varying (Isaksen, 2003).

4. DISCUSSION AND CONCLUSION

Six important attributes of sustainability in the Norwegian cod-fishing fleet have been identified in this paper. The vessel groups, A-E, are evaluated, accordingly:

1. Green-house gas emissions: The largest vessels, using active fishing gear, have the highest fuel consumption per kg fish.
2. Profitability: The smallest vessels have the highest earning capacity.
3. Employment: The smallest vessels employ more people in all, even though the largest vessels have more employees per vessel.
4. Accident risk: The fatal accident rate is very high for the smallest vessels.
5. Catch capacity: The catch capacity is naturally highest for the largest vessels.
6. Quality: The quality of the fish meat is influenced by many factors, such as the catching gear. Investigations show that the fish caught by net gives the lowest quality, whereas the fish caught by hand line gives the best quality. In general, it seems as the trawlers attain higher average prices for the fish than the small conventional vessels.

Fisheries management should be able to assess the effectiveness of its objectives. Use of performance indicators may simplify such evaluations. Identification of performance indicators in the systems engineering process is based on determining the requirements to the system; in this case a sustainable fishing fleet. The Norwegian fisheries management aims at reducing overcapacity by efforts of structural changes. The effects of such efforts should be monitored in order to assess the consequences. Effective implementation presupposes that the efforts increase sustainability in the fishing fleets. There is a lot of information available about the Norwegian fisheries; however, the data are not presented as means of evaluating the performance of fisheries management related to goal achievement over time. Thus, the discussion in this paper has visualized and evaluated some important attributes of sustainability in the cod-fishing fleets, which may contribute to a better decision basis for fisheries management.

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