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A sustainability assessment framework for genome-edited salmon

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ABSTRACT

In this paper we present a suggestion for a sustainability assessment framework using genome editing of salmon as a case study. The salmon farming industry is facing several challenges hindering sustainable production. Genome editing has entered as a tool that can improve selective breeding and feed ingredients in aquaculture, hence providing solutions such as resistance to salmon lice and other pathogens, and sterility reducing interbreeding with wild, threatened stocks. As a goal for aquaculture is that its practices and products contribute to sustainability, the use of genome editing needs to be assessed with regards to sustainability, too. In our work, we draw on three sources of information; strategy and policy documents published by governmental offices and industry organizations; relevant GMO regulations and operationalization reports; and qualitative empirical data from 19 semi-structured interviews with Norwegian key stakeholders, and four semi-structured citizen groups. The findings from our analyses are discussed in relation to a Wedding cake-model for sustainability developed at the Stockholm Resilience Centre based on the UN SDGs and the three pillars of sustainability: biosphere, society, and economy. Analysis of document and interview data shows three main findings, one within each of the sustainability pillars. First, we identified that the biosphere pillar, including protection of the environment and the wild salmon, is the major sustainability issue and therefore important for the assessment of sustainability in the aquaculture industry and for the potential introduction of genome-edited salmon. Second, in the pillar for society the preservation of cultural and natural resources should be included, and in the Norwegian context this includes preserving the Sámi culture reliance on the wild salmon stocks. Third, in the economy pillar animal welfare needs to be included both for efficiency and ethical responsibility in farming. With some adoption to local and national conditions and the fish species in question, the same framework can be used for sustainability assessment of genome edited finfish in general.

1. Introduction

Aquaculture is becoming the primary source of seafood and has the potential to be crucial in the transition to a sustainable global food system (BFA, 2021). One of the important species groups are Salmonids (Golden et al., 2021; FAO, 2022), and Norway is at present the largest producer of Atlantic salmon (*Salmo salar*, from here just salmon) globally (Iversen et al., 2020). Globally, production of salmon covers 32.6% of the total production of marine and coastal farmed fish (FAO, 2022). The Norwegian production of salmon is a young industry with an attributed blooming potential. The production increased from an input of 98,000,000 individual salmon in 1995 to 388,000,000 individuals in 2020 (Directorate of Fisheries, 2022, *Input 1994–2021)*. The value on slaughtered fish reached 64 billion NOK (approximately 6,3 billion Euros) in 2020 (Directorate of Fisheries, 2022, *Sales 1994–2020*). The industry employs 7103 people (2020) in Norway, mainly in the three northernmost counties and on the west coast, which is double the number of employees compared to 2010 (Directorate of Fisheries, 2022, *Number of Employees 1994–2020*). It is considered one of the most important and valuable industries in Norway, both for national value creation and for local communities (Ministry of Trade, Industry and Fisheries, 2021). The salmon farming industry is facing several challenges hindering sustainable production, such as salmon lice (*Salmonis lepoptheiruis)*, viral and bacterial diseases affecting welfare of the farmed fish (Sommerset et al., 2022). According to the annual fish health report by the Norwegian Veterinary Institute (Sommerset et al., 2022), 54 million farmed salmon died before slaughter in 2020, and they state that it is crucial to focus more on the welfare of the fish, rather than the size

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of the produced biomass. The most severe environmental impact the industry has is related to escapees and spread of disease from farmed to wild salmon. The farmed salmon standing biomass exceeds the wild stocks several hundred times over (Grefsrud et al., 2022), which leads to an immense selection pressure for bacterial, viral and parasitic pathogens such as infectious salmon anemia virus and the salmon lice (Thorstad et al., 2021), pathogens affecting welfare and that will spread to the environment and the wild stocks. In 2021, 61,133 salmon escaped (Directorate of Fisheries, 2022, *Losses in production*) and some of these may also have negative ecological and genetic effects on wild stocks (Bradbury et al., 2020), which can lead to a decline in wild populations (Thorstad et al., 2021). The wild salmon in Norway is at present considered to be an endangered species, and entered the Red List as *near threatened* in 2021 (Hesthagen et al., 2021). Another challenge is feed, although the use of fish meal and oil has been reduced, the industry is still dependent om imported feed resources as soy, showing the importance to find alternative feed ingredients of superior quality from local sources (Albrektsen et al., 2022).

Genome editing has entered as a tool that can increase efficiency and improve selective breeding. It holds promises for novel approaches to vaccine development, for increased nutritional content in aquaculture feed, and for removal and/or introduction of traits in aquaculture breeds such as salmon. Genome editing is a term covering several gene technologies which are used to change genetic sequences in vivo or in vitro of an organism or cell. Currently, CRISPR/Cas (Clustered Regularly Interspaced Short Palindromic Repeats/CRISPR associated proteins) (Doudna and Charpentier, 2014) is the most used genome editing technology in research on aquaculture finfish (Blix et al., 2021), for thorough overviews of application in finfish please see e.g., Blix et al. (2021), Hallerman (2021), Okoli et al. (2021), Yang et al. (2021). Genome editing technologies are separated from older techniques such as genetic modification (GM) because genome editing techniques are faster and more targeted (Okoli et al., 2021). Different changes can be introduced in the genome as for example site-specific mutations with non-homologous end-joining (NHEJ) termed Site Directed Nucleases (SDN)-1. Alternatively, a shorter or longer stretch of genetic sequence from the same species or from other species can be inserted together with the SDN, and the breaking of the DNA leads to insertion of short or long genetic sequence (SDN-2 or SDN-3) through homologous-directed repair (HDR) (EFSA, 2012).

Salmon is one of the most researched aquaculture species in this field, with Norway as head of the research. Currently, the traits which are most researched using genome editing for this species is sterility and pigmentation (Blix et al., 2021). Sterility entails a solution to one of the environmental concerns as sterile salmon cannot breed with wild populations after it escapes (Blix et al., 2021; Güralp et al., 2020; Wargelius, 2019), while pigmentation is relevant as a tool for research. Other solutions currently under research are salmon lice resistance (Nofima, 2021b), CMS (cardiomyopathy syndrome) resistance which is the main mortality factor in Norwegian industry today (Nofima, 2021a; Sommerset et al., 2022), and enhanced omega-3 production (Datsomor et al., 2019a, 2019b; Jin et al., 2020). Thus, genome editing holds promises for improving the sustainability and efficiency of the salmon industry by reducing impact on wild stocks and improve animal welfare.

The novelty of genome editing has triggered discussions on the adequacy of present GM legislation and if there is need to label products based on genome editing as GM (Turnbull et al., 2021). As our case study is genome editing of salmon aquaculture in Norway we adhere to a Norwegian legal context. Norway has its own Gene Technology Act of 1993 (GTA; Ministry of Climate and Environment, 2005a), follows EU GMO directives through the EEA agreement, and are signatories to the international Cartagena Protocol, a legal context where a genome-edited salmon is considered to be a new type of genetical modification. The GTA includes requirements for ethical justifiability, social utility and contribution to sustainability. The assessments of these three criteria are currently under discussion (Antonsen and Dassler, 2021). In addition, even though genome-edited organisms might be (partly) excluded from GMO legislation in Norway (Bratlie et al., 2019), as it has been on a case-by-case basis in the U.S. and Argentina, it can still be argued that genome-edited organisms should be assessed for their contribution to sustainability considering the disruptive nature of the technology (Myskja and Myhr, 2020). From this follows the question, what is needed for a sufficient sustainability assessment of genome-edited fish?

Recent years it has been a focus both by governmental agencies and the industry on the need to enhance sustainability in aquaculture practices and products. As with increased focus, the objectives and indicators for the assessment of sustainability is evolving. At the same time, it is recognized that indicators and assessment frameworks need to be contextual and dependent on the type of aquaculture system applied, as well reflect the aquacultured species as there are huge variations between them regarding their requirements for handling, feed and environmental conditions. Our analysis use farmed genome-edited salmon in Norwegian ocean facilities as a case with the purpose of elaborating a sustainability assessment framework for genome-edited salmon in aquaculture using three sources of information; strategy and policy documents published by governmental offices and industry organizations; relevant GMO regulations and operationalization reports; and qualitative empirical data from 19 semi-structured interviews with Norwegian key stakeholders, and four semi-structured citizen groups. This work contributes to the growing knowledge on stakeholder and citizens views on genome-editing in food production (Bearth et al., 2022; Busch et al., 2022; Kantar., 2020; van der Berg et al., 2021), and to the more general discussion of how to operationalise sustainability in aquaculture.

2. Theory: Sustainability in policy and regulation

Sustainability has been set as a prerequisite for the future life of humans on Earth. It is a term which is widely used, defined, and understood, and it is a leading aim for the development of "green" industries. Historically, the term sustainable development is of young age, but the wider meaning of sustainable development, resource use and human interaction with Earth systems can be found centuries back (Du Pisani, 2006). In the 1980-ties the World Commission on Environment and Development was asked to formulate a "global agenda for change" (Brundtland et al., 1987). The resulting report *Our common future* aimed at defining common ideas about how to combine development with environmental conservation. The definition of sustainable development was defined as development that "[…] meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987, chapter 1). After this, sustainable development was successively operationalized in common goals. In 2015, the UN redefined the Millennium Goals into 17 sustainable development goals (SDGs) in *Transforming our World: the 2030 Agenda for Sustainable Development*, from here just Agenda 2030 (UN, 2015). These are based on the thoughts of Brundtland et al. (1987), and are developed for all countries with the aim to have common guidelines on how to achieve a sustainable earth. There are 17 people-centred goals with 169 targets in total. The SDGs are integrated in each other, emphasizing that *everything depends on everything*, and balance the three dimensions of sustainable development: environmental, economic, and social (UN, 2015).

2.1. Sustainability in aquaculture policy

Several initiatives and organizations (e.g., FAO, 2022; BFA, 2021) have pointed to seafood as crucial for future sustainable food production. Globally, the Ocean Panel has stated that seafood should be increased by a six-fold by 2050 (Stuchtey et al., 2020). This expansion requires reducing negative environmental impacts from aquaculture and enhancing sustainability in the industry. The Norwegian Government recently published a strategy where they call for «[…] increased growth in the aquaculture industry within sustainable limits" (Ministry of Trade, Industry and Fisheries, 2021 p. 8, our translation). Even though the strategy opens with referring to the Ocean Panel calling for the necessity of more seafood to feed a growing population, the arguments for producing salmon along the Norwegian coast are related to national value-creation, sustaining local coastal communities, and creating an income for the common good (Ministry of Trade, Industry and Fisheries, 2021). According to the strategy, environmental sustainability should be of main priority. The Government also look to the EU taxonomy for sustainable economic activities (EU Technical Expert Group on Sustainable Finance, 2020), even though criteria for aquaculture are not yet included in this taxonomy. This is one way of ensuring the aquaculture to move in a more sustainable direction, by directing the capital to "green" investments only (Ministry of Trade, Industry and Fisheries, 2021).

Within aquaculture there has been developed several voluntary certification schemes, which represent a different way to measure how sustainable the industry is (Amundsen and Osmundsen, 2018). Within this system, aquaculture producers need to comply with given indicators and standards adopted to different aquaculture systems to achieve a certification. For salmon aquaculture there are eight major certification systems, these includes the Aquaculture Stewardship Council and Global Aquaculture Alliance. Amundsen and Osmundsen (2018) analysed indicators of the eight major certification schemes. They identified 28 topics, grouped in relation to governance (50% of the indicators), environment (47%), economics (3%) and culture (1%). Within these certification schemes the focus is on the environment (including fish health and welfare), while social implications are almost not included (Amundsen and Osmundsen, 2018; Amundsen, 2022).

2.2. Regulation and sustainability assessments of GMOs

Internationally, living modified organisms (LMO) (equivalent with genetically modified organisms (GMOs) and genome-edited organisms), are regulated by the Cartagena Protocol on Biosafety (CPB) to the Convention on Biological Diversity (CBD). The main objective of the CPB is to protect biological diversity against LMOs as these organisms are moved between countries. The CPB has 173 signatories, including Norway and excluding the U.S. and China (CBD, 2020), which are the top 3 countries researching genome editing of aquaculture finfish (Blix et al., 2021). The CPB defines biosafety as a term which ensures safe use of modern biotechnology considering human health and the environment, while at the same time recognizing the possibilities that such technologies might offer (CBD, 2000). According to Article 16 Risk Management of the CPB, all signatories shall create mechanisms and systems for identifying LMOs or traits in such organisms that might "[…] have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health […]" (CBD, 2000, Article 16). However, at present no specific guidelines for risk assessment of LMO fish has been implemented. The CPB includes socio-economic considerations in Article 26 specifying that this is related to the impacts on "[…] the conservation and sustainable use of biological diversity, especially regarding the value of biological diversity to indigenous and local communities" (CBD, 2000, Article 26). A dedicated expert committee has been assigned to work on socio-economic consideration, and they have suggested a specific guideline for the process (CBD, 2019), but not developed any indicators or specific guidelines for any LMOs.

In the EU, genome-edited organisms are currently regulated as GMOs after a Court decision in 2018 (Court of Justice of the European Union, 2018). Therefore, an application of commercial use of a genome-edited organisms must follow a risk assessment in accordance with the regulation, a process that for which the European Food Safety Authority (EFSA) has developed guidance's. EU regulation of GMOs, here included GM plants, microorganisms and animals, covers contained use, deliberate release, labelling and food safety. In addition, member countries can restrict or prohibit the production of GMOs instate (Directive EU 2015/412), based on e.g., concerns for socio-economic consequences in line with non-safety related concerns. Recently the commission has initiated work on a new legislation for plants produced by certain genomic techniques (EC, 2021) where sustainability assessment is suggested to be included.

At the national level, different GMO regulatory frameworks have been developed (Ishii and Araki, 2017). In Norway, the production and use of GMOs is regulated by the Norwegian Gene Technology Act of 1993 (GTA) (Ministry of Climate and Environment, 2005a). Currently, genome-edited organisms are treated as GMOs as in the EU. Norway was one of the first countries adopting non-safety factors and has the longest experience with sustainability assessment of GMOs. The GTA requires that the GMO, besides being safe for health and environment, must contribute to sustainable development, is ethically justifiable and has societal utility – three non-safety criteria in the Act. The procedure for the evaluation of the non-safety criteria is given in appendix 4 to the *Regulations on impact assessments of the Gene Technology Act* (Ministry of Climate and Environment, 2005). The Norwegian Biotechnology Advisory Board (NBAB) is responsible for advising the Ministry on new applications regarding the non-safety criteria. For this task, they have operationalized the guidelines for assessments of contribution to sustainability and for societal utility (NBAB, 2009, 2014, 2018). After a request from the Norwegian Environment Agency, an expert group has suggested how the ethics criterion can be operationalized (Forsberg et al., 2019).

The framework for sustainability assessment (NBAB, 2009) includes control questions within five core ideas, and for each core idea there are correlated control questions regarding both production and use of the GMO. The framework has been used as a starting point for the assessment of different plants and adapted to their characteristics and cultivation context (NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016). At present there are no guidelines for the assessment of GM animals (Blix and Myhr, 2021; Blix et al., 2021). In Table 1 from Blix and Myhr (2021) core ideas from the official NBAB framework have been combined with main topics elaborated for a diversity of GM plants. The table indicates that these guidelines can be used as a starting point for the assessment of GM animals, however, animal welfare needs to be further elaborated as these guidelines only covers impacts on animal welfare by consumption of feed based on GM plants.

2.3. Stakeholder and citizen involvement in sustainability assessment

In addition to normative data found in policy documents, it is important to look to descriptive, empirical data from engagement with relevant stakeholders, including citizens, to develop a sustainability assessment framework. This aims to ground the assessment in practices and values. Such an inclusion will provide that diverse needs and concern will be identified, and such interaction can improve adaptation, and flexibility in translating local practices into frameworks or sustainability schemes (Amundsen, 2022). Inclusion of stakeholders and citizens will also provide crucial information in assessment about local environmental conditions as well as local and traditional knowledge (Olesen et al., 2011). As described by Myrvold et al. (2019), the salmon is also of great cultural and social importance in Norway, and it is an important ecological and cultural species in Sámi culture (Sámi Parliament, 2021), the indigenous people in Norway. In addition, earlier research on the production of farmed salmon in Norway and Tasmania by Lien (2015) shows that people working close to the salmon in the farming industry expresses care towards and about the farmed salmon, hence providing information that can explain or supplement written materials. Such participatory approach is also of high value for the assessment of novel technologies as they will provide an appreciation of ethical and social values, as illustrated by Bremer et al. (2015) in their study on GM salmon.

Table 1
From Blix and Myhr (2021): Combination of NBAB sustainability guideline document (2009) with relevant topics developed for specific GM crops (NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016).

Original guideline document (NBAB, 2009)	Operationalization of guidelines: Report on plants adapted to salmon (NBAB, 2011, 2014, Catacora-Vargas, 2014, Gillund and Myhr, 2016).	
	Pillars	Topics
Global effects	Ecology and environment	The genetically modified organism
Ecological limits		Interaction between the GM and the environment
Basic human needs		Gene flow to wild relatives
Distribution between generations		Preservation of biological diversity in ocean and rivers
Distribution between rich and poor		Resistance in salmon to diseases and parasites
(For all core ideas: Do these effects differ between production and use?)		Comparison with control salmon (farmed)
		Safety of human health and the environment over time
	Economy and society	The right to sufficient, safe and healthy food
		Animal welfare*
		Living conditions and profitability for fish farmers and coastal communities in short and long terms
		Biodiversity and genetic resources for food and aquaculture
		Independent risk assessment
		Freedom to choose a different aquaculture system in the future

* *Animal welfare is a topic in* NBAB (2014) *and Catagoras-Vargas (2014). However, this was regarding the use of the evaluated plant for animal feed, not for a GM animal.*

3. Materials and methods

The making of the framework for assessment of sustainability is based on policy documents, strategies, and reports from governmental offices, agencies and interest groups related to either aquaculture, food production or natural resource management. In addition, the topics and control questions necessary for the assessment has been rooted in empirical data from semi-structured interviews with 19 stakeholders and four citizen groups. Interviews with stakeholders and citizen directly or indirectly involved with the salmon farming was carried out as this was considered to provide important knowledge and to give a fuller understanding of how sustainability is perceived, supplementing the documents. For developing the framework, we used the previous GM crop reports as a starting point (NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016). In addition, we hypothesized that it would be useful to base the framework on the UN SDGs and the Wedding Cake-rearrangement of the SDGs (Rockström and Sukhdev, 2016). Aspects, topics, or relevant questions identified in the documents, reports and in the interviews were therefore systematized according to whether they answered to either the biosphere, society, or economy. Accordingly, analysis of the documents and interviews also included identifying ways of defining sustainability to be used for the elaboration of the structure of the framework.

3.1. Policy documents

Documents were used to supplement the empirical interview data (Bowen, 2009), and were identified both before, during and after the interviews were conducted. The documents were chosen based on two necessities: First to identify how sustainability is understood and operationalized generally, both on a global and national (Norway) basis. Second, we needed documents that could be used to identify how sustainability could be operationalized in aquaculture. On global level we chose documents connected to the UN and the EU published after the UN SDGs in Agenda 2030 (UN, 2015). On national level we chose documents produced by the Norwegian government, the Sámi Parliament, and a strategy made by an industry federation for the aquaculture sector. The 9 final documents were not systematically selected and therefore some relevant documents may have been left out.

The authors read each their documents, searching for text describing *a) sustainability,* and b) *sustainability in aquaculture* in order to identify what is conceived as requirements for a system or product to be sustainable. The text sampled was used to elaborate an appropriate structure of the framework, and to elaborate topics to be used for assessing contribution to sustainable development. For the latter, the topics to include in the assessment were written in the form of (control) questions, as this is more appropriate for the assessment format and has previously been done in the GM crop reports (NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016). This was performed by condensation of statements in the documents which could be related to sustainability. The condensed statements were merged across the different documents and re-stated into control questions. Only those documents mentioning animal welfare has been used to inform the discussion on how to relate animal welfare to sustainability.

3.2. Qualitative interviews

3.2.1. Study design

The study was conducted as part of a larger study on genome editing of farmed salmon (project CRISPRsalmon: https://www.ntnu.edu/crispr-salmon). Semi-structured, explorative interviews were conducted with stakeholders of the salmon farming industry and with citizens in group interviews. Involving stakeholders and citizens in the research ensures that it is inclusive and rooted in real-world experiences of what it means to produce and consume farmed salmon, and to protect farmed and wild salmon, and nature. Initially, focus group interviews were planned to generate data via interaction between group members. However, because of the COVID-19 pandemic, all interviews had to be performed on video link. The main flow of communication during interviews took place between moderators and participants one by one, reinforced using the "raise-hand"-function in the video meeting software. We therefore have analysed and refer to the focus group interviews as group interviews.

The interviews covered both personal, ethical and sustainability aspects of farming salmon, but here we present only findings more specifically related to sustainability. While the strategy documents present normative views on what the industry should look like from the point of view of policymakers and stakeholders, the qualitative interviews present the more personal views of individuals involved in or with the industry, including citizens. It follows, that the views may align with, but should not be seen as representative of stakeholder or citizen views (Brinkmann and Kvale, 2014 p. 127).

3.2.2. Interview guide

The semi-structured interview guide (Brinkmann and Kvale, 2014) was developed pre- and in parallel to the recruitment process. The questions planned were systemized according to three themes: animal welfare and relations to salmon, genome editing, and sustainability. The guide is briefly described in the following list:

- For the theme animal welfare and relations to salmon we asked what the participants thought of the salmon as an animal and about their personal relationship towards it, what fish welfare is and how to practice it, and differences between fish and terrestrial animals with regards to this.
- For the theme genome editing we asked about advantages and/or disadvantages by genome editing of the farmed salmon, differences between the genome editing technology and older modification

techniques, differences between conventional breeding and using genome editing, intrinsic value and whether using genome editing is wrong, and whether they would buy genome-edited salmon if available.

- For the theme sustainability we asked participants to elaborate what sustainable development is (to them), whether a genome-edited salmon could contribute to sustainability, and whether they could see connections between sustainability and animal welfare.

3.2.3. Recruitment of participants

For *the stakeholder interviews* relevant stakeholder groups were identified during the search for relevant documents. The main stakeholder groups identified can be viewed in Table 2. Before recruiting participants, the Norwegian Centre for Research Data (NSD) was notified about the sampling and use of personal information (NSD reference number 707095).

From the analysis of the strategy documents relevant candidates within each stakeholder group were identified as individuals holding leading positions. Further, snowball recruitment was performed using declining and accepting candidates, members of the research group, and fellow advisors as mediators. The invitation letter included information about the project and a declaration of consent to be signed by the participants. Date for interview were agreed over email. In total, 38 candidates were invited to participate, whereof 19 responded positively and participated in an interview, from here *participants*. The remaining 19 candidates declined or did not respond to the invitation, or responded positively first, but then didn't respond to further communication. Reasons given for declining were lack of time, self-perceived bias or fear of their personal opinions being leaked to the public. Table 2 shows the number of participants in stakeholders and citizen groups. The number of participants per stakeholder group varies because groups which work directly with salmon on a daily basis and groups whose information could not be found by a literature search were prioritized.

For the *group interviews with citizens*, identification and recruitment of participants was performed by IPSOS, a world-wide marketing analysis company well experienced in marked surveys. For three of the groups, IPSOS recruited individuals from the Norwegian population, from different regions in Norway, and with maximum variation according to age (18–80), genders and ethnicity. A fourth group was recruited with people who only have Sámi background in addition to the criteria above. Recruitment was done from IPSOS panel of people already consent to participate in focus groups, and by "snowballing" from declining candidates using them as mediators. In addition, targeted Facebook ads and search in relevant Facebook groups with and without "snowballing" was done. Relevant and accepting participants were informed about the practical details concerning the focus group per email. Extra recruitment was done for all groups, to ensure adequate participation in case of insufficient turnout. Selected participants signed a standard declaration about GDPR and how data is stored generated by IPSOS. Final selection of participants was made on the day of interviews and aimed to ensure relevant spread of geographical location, age, and gender. Participants not selected for participation were compensated with the same 500 NOK (approximately 49 Euro) voucher as participants that were selected.

Table 2
Interview groups with reference code used in Table 4 and number of interviews per group.

Groups	Reference code	Number of interviews
Scientists using genome editing in fish	SGE	4
Trade union participants	TUR	2
Salmon farmers	SAF	4
Fish health workers	FHW	3
NGO-participants	NGO	2
Advisory body participant	ABR	1
Sami resource management	SRM	1
Wild salmon management	WSM	2
Citizen group Norwegian	CGN	3×6
Citizen group Sámi Norwegian	CGS	1×6

For citizen groups the number shows number of groups × number of participants per group.

3.2.4. Interviews

The individual interviews with stakeholders were held in digital videocalls over Zoom or Teams by researchers from the CRISPRsalmon project and lasted for about an hour. All stakeholder participants had to sign a declaration of consent as part of the NSD requirements for data sampling through qualitative interviews. The interviews were audio recorded and transcribed verbatim by project researchers.

The group interviews with citizens were conducted in digital videocalls using the same interview guide as in stakeholder interviews. Researchers from the CRISPRsalmon project were moderators, and representants from IPSOS participated as practical helpers and note-takers. Interviews were audio recorded. During the interviews IPSOS took extensive notes and modified them afterwards drawing on the audio records to provide more detailed transcripts. Group interview transcripts were not verbatim.

3.2.5. Analysis

The aim of the present analysis was to generate suggestions for control questions to applicants for commercial use of genome-edited salmon, which could be used directly in a sustainability assessment framework, as previously done (NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016). The interviews were coded post transcription using the terms concern/criteria, looking for all kinds of statements which could be read as either a concern regarding or criteria for accepting the use of genome editing on farmed salmon. The coded segments where then analysed by grouping the statements into the following themes *technology-related concerns, sustainability, societal utility* and *other concerns*. We performed a condensation of meaning (Brinkmann and Kvale, 2014, p. 231–235) by grouping statements related to sustainability which were similar across stakeholder and group interviews. Subsequently, the statements were merged and re-stated into control questions ((Brinkmann and Kvale, 2014), p. 231–235). Statements made by participants would take different forms, and they were not always made directly regarding sustainability. However, during analysis of meaning, statements were found to be linked to sustainability challenges. An example of this is animal welfare which could be considered part of an ethics assessment. However, based on our previous work (Blix and Myhr, 2021), this was considered a topic under sustainable economy as it is important for improving production efficiency and ensuring having a responsible production and consumption (UN SDG 12). Some of the concerns/criteria identified in the analysis were not appropriate to re-state into single control questions, but rather had the form of general topics of sustainability.

3.3. Making a sustainability assessment framework

In the aftermath of the Agenda 2030, Rockström and Sukhdev (2016) remodelled the SDGs in a model that aims to explain how the goals are linked to food production. Fig. 1 shows this model. The intention by the model is to re-shape approaches and considerations of sustainability, and it implies other requirements for institutions and industries who wants to assess how their work contributes to the goals and prohibits the "shopping" of the most relevant/suitable goals. According to Rockström and Sukhdev (2016) this model represents a new way of viewing the three pillars of sustainability. The "wedding cake" is an iconic figure developed at Stockholm Resilience Centre by Folke (Folke et al., 2016). The model represent how economy serves society in order for society to evolve "[…] within the safe operating space of the planet" (Rockström and Sukhdev, 2016). This model is used as the foundation of the framework generated here. In the framework, the control questions generated by analysis of interviews and documents are merged with

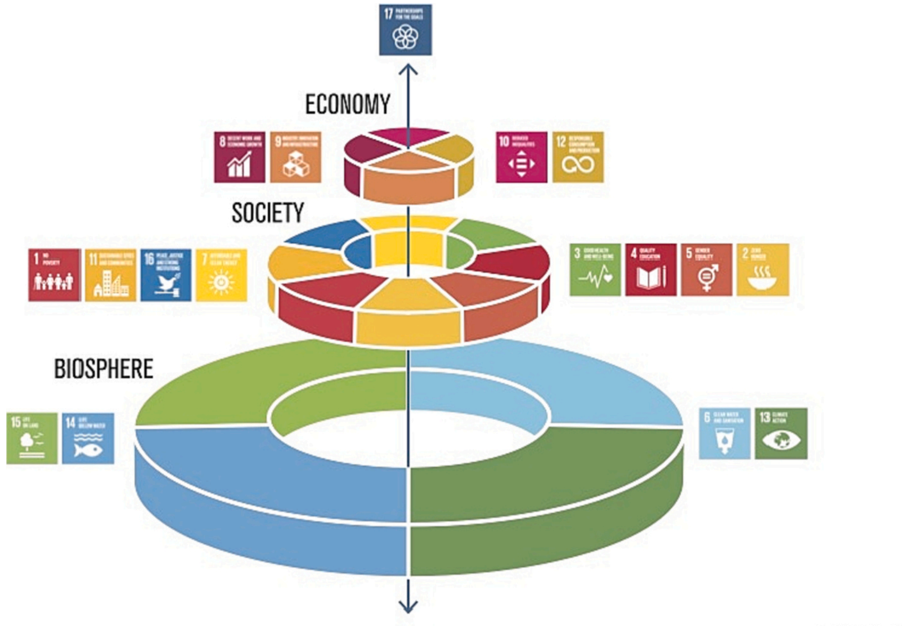

Fig. 1. Restructured model for the UN SDGs by Rockström and Sukhdev (2016), illustration by Azote for Stockholm Resilience Centre (CC BY 4.0).

control questions from pre-existing frameworks (Ministry of Climate and Environment, 2005; NBAB, 2011, 2014; Catacora-Vargas, 2014; Gillund and Myhr, 2016). Finally, the control questions were structured into respective *topics* and the topics were placed within the more appropriate level of sustainability – biosphere, society or economy, based on the SDGs within each level (see Table 4).

4. Results and discussion

In this section we will present and discuss how the results from the analyses of interviews and documents can inform a sustainability assessment framework for genome-edited salmon. Considering the scope of the data reviewed for the making of the framework, this paper will not

Table 3
Documents retrieved in document search.

Document groups	Document title	Reference	Target groups	Related documents (examples)**
Global sustainability	*Transforming our World: the 2030 Agenda for Sustainable Development*	UN (2015)	All countries and stakeholders	*Millennium Development Goals* (UN 2000), *Universal Declaration of Human rights* (UN 1948)**
	Farm to Fork Strategy (here: FF)	(EC, 2020)	European policy makers and citizens	European Green Deal (2019)**, Agenda 2030 (UN, 2015)
	Building Blue Food Futures for People and the Planet (2021) (here: BFA)	Stockholm Resilience Centre, Stanford University, EAT (BFA, 2021)	Policy makers globally	*Agenda 2030 (*UN, 2015*), Food security and nutrition: building a global narrative towards 2030* (HPLP 2030)**
	Mission Starfish 2030: Restore Our Oceans and Waters (here: Starfish)	European Commission et al. (European Commission et al., 2020)	European policy makers and citizens	IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019)**, Global assessment report on biodiversity and ecosystem services of the IPBES (2019)**, European Green Deal (2019)**, *Agenda 2030* (UN, 2015)
National government on sustainability	*Food, Humans and Environment. Norwegian actions plan for sustainable food systems in developmental politics and foreign affairs for 2019–2023**(here: FHE)*	The Norwegian Governmental Ministries (2019)	National authorities	*Agenda 2030* (UN, 2015), Paris agreement (2015)**, Sendai Framework for Disaster Risk Reduction (2015)**
	*Sámi Parliament Statement on Area and Environment: Meahcci – a foundation for identity, culture and birgejupmi**(here: SPA)*	Sámi Parliament (2016)	All Sámi Parliament activities	Sámi Parliament Statement on Area and Environment (2009)**, CBD (2000), The Norwegian Nature Diversity Act (Ministry of Climate and Environment, 2009), The Finnmark Act (2020)**
National government on aquaculture/ salmon	*An Ocean of Possibilities – The Governments Aquaculture Strategy**(here: NGAS)*	Ministry of Trade, Industry and Fisheries (2021)	National, local and regional authorities, research, management and the aquaculture industry.	*Transformations for A Stable Oceans Economy* (Stuchtey et al. 2020), Agenda 2030 (UN, 2015), The Granavolden Platform (2019)**
	*Sámi Parliament Statement on Salmon: Diddi, lousjuolgi, goadjin ja duovvi**(here: SPS)*	Sámi Parliament (2021)	All Sámi Parliament activities regarding cases of wild salmon management/farming of salmon	Agenda 2030 (UN, 2015), CBD (2000), ILO Convention no. 169 (1989)**, International Covenant on Civil and Political Rights (UN 1966)**
Aquaculture industry strategy	*Roadmap for Aquaculture (here: NI)*	The Federation of Norwegian Industries (NI, 2017)	All member companies	Agenda 2030 (UN, 2015)

* Document is only available in Norwegian, our translation of title, original title in reference list.
** Documents are not used in text elsewhere and therefore not listed in references.

go into detail on all topics and control questions. This section first presents and briefly discusses the most important results from documents and interviews, respectively. Then we discuss the two topics which stands out: indigenous and local people's knowledge and rights and animal welfare. Quotations presented here from the documents published in only Norwegian, and from the interviews except two, are based our translation.

4.1. Policy documents

The documents identified and analysed are presented in Table 3. The documents have been grouped into different categories based on the target group they approach; on what level they have been produced, and according to the level of the challenges they discuss. Based on these criteria the following groups and documents were identified:

- Global sustainability documents are the UN Agenda 2030 (UN, 2015), The Farm to Fork Strategy (EC, 2020), the EU document Mission Starfish 2030: Restore Our Oceans and Waters (European Commission et al., 2020), and the Blue Food Assessment Summary Report (BFA, 2021). These global documents are used to identify how sustainability is, and could be, understood and operationalized on a global level, with specific emphasis on food production systems, oceans and marine food.
- National documents are Food, Humans and Environment, Norwegian actions plan for sustainable food systems in developmental politics and foreign affairs for 2019–2023 (The Norwegian Governmental Ministries, 2019), and Sámi Parliament Statement on Area and Environment: Meahcci – a foundation for identity, culture and birgejupmi [*to get by*] (Sámi Parliament, 2016). These documents contribute to the description of how Norway perceive and operationalise sustainability on the governmental level, including the Sámi resource management.
- Governmental documents on aquaculture/salmon, here represented by the Norwegian government in An Ocean of Possibilities – The Governments Aquaculture Strategy by Ministry of Trade, Industry and Fisheries (2021), and the Sámi Parliament Statement on Salmon: Diddi, lousjuolgi, goadjin ja duovvi (Sámi Parliament, 2021). The former focuses on aquaculture production of fish, while the latter on wild fish management, and are therefore not comparable, but both gives information about Norwegian salmon management.
- Finally, we have identified a strategy, amongst many, on aquaculture, written by one of the trade unions, The Federation of Norwegian Industries Roadmap for Aquaculture (NI, 2017).

Since the nationality in question is Norway, we acknowledge that if the framework was to be based on the politics and food production system of another country, other documents would be analysed, and other challenges approached. However, considering the inclusion of global documents, the framework will be relevant for other countries and a diverse system of animal protein production as well. This list of documents in Table 3 is not exhaustive, but the documents identified all contribute to describe how to define and operationalise sustainable development from a global to a local level.

4.1.1. Different routes to sustainability in aquaculture

Table 3 lists related documents for each identified document, showing both the context and the background for the documents. The Agenda 2030 (UN, 2015) have been cited in all identified documents, except the Sámi Parliament Strategy on Area (Sámi Parliament, 2016). We find that this clearly indicate the usefulness of utilizing the 17 UN SDGs for assessment of sustainability. The SDGs have been criticized for setting goals that are not possible to measure, for being too ambiguous, having a complicated language, being non-binding, and for top-prioritizing everything leaving nothing to be main priority (Swain, 2018). When implementing the SDGs into an organisation, an industry, a supply chain or the like, it is inevitable that there is a need for focusing the sustainability work, making some internal goals within the common goal of achieving a more sustainable Earth. When the global "receipt" for sustainable development is 17 goals within different areas - ocean, health, equality, production, and consumption and so on, it is also inevitable that industries solve the task of operationalising sustainability by picking those goals that they feel connected to and responsible for. The problem with such a solution is the risk of using a fragmented approach and overlooking systemic effects. Can an industry really ensure sustainable development in their production if they only focus on equality or production and consumption? This is identified in some of the other documents. The Federation of Norwegian Industries document *Roadmap for Aquaculture* (NI, 2017) states that important SDGs for their work are 2: Zero hunger, 3: Good health and well-being, 13: Climate action, and 14: Life below water (NI, 2017). Similarly, the Sámi Parliament Statement on Salmon (Sámi Parliament, 2021) emphasizes SDG 14, and the Norwegian Sustainability Strategy on Food, Humans and Environment (The Norwegian Governmental Ministries, 2019) states that SDG 2 is most important. The latter document does, however, emphasize that food production involves all SDGs, which has also been stated earlier by Rockström and Sukhdev (2016) as "[…] food connects all the SDGs".

A possible consequence of this prioritization of SDGs is a narrow assessment of how a sustainable system should be build. If this is transferred to an assessment framework it can give a skewed impression of what sustainability is. This has also been shown by Amundsen (2022) with regards to aquaculture certification standards where the pitfall is that «[…] the map becomes the terrain» if the assessment is reduced to a rigid scheme (Amundsen, 2022). Amundsen summarizes related papers looking at the certification system for aquaculture and finds that certification standards is most valuable when acknowledging that these are simplifications of reality (Amundsen, 2022). The assessment of genome-edited salmon is different from certification standards as it is performed pre-commercialization, however, the principle of checking boxes in a scheme is similar. A framework should not be a rigid list of questions, nor focus on singular SDGs. Having a clear, fundamental idea about what sustainable development is could be helpful in order to maintain some flexibility in the assessment process.

4.1.2. Documents propose biosphere-focused framework

Considering the discussion above, we have analysed the documents for how they define sustainability, directly or indirectly. The analysis shows the importance of the biosphere in most documents, albeit the strategies might differ.

The Food, Humans and Environment document focuses on how food is relevant for several of the SDGs and brings food production into global affairs and developmental politics, thus inserting Norway in the larger picture and as part of the global food systems. The three pillars are here said to be equally important (The Norwegian Governmental Ministries, 2019). The same focus is found in the Farm to Fork strategy, which also includes reflection on the COVID-19 pandemic showing connections between "[…] our health, ecosystems, supply chains, consumption patterns and planetary boundaries". The strategy points out that increasing sustainability will enforce resilience, and that solutions should be nature-based, technological, digital and space-based (EC, 2020).

The need to, and importance of, preserving and protecting ecosystems in resource management, protecting wild salmon and protecting ecosystem services is raised by the Farm to Fork strategy (EC, 2020), the EU Mission Starfish (European Commission et al., 2020), the Governments Aquaculture Strategy (Ministry of Trade, Industry and Fisheries, 2021), the action plan Food, Humans and Environment (The Norwegian Governmental Ministries, 2019), and the Agenda 2030 (UN, 2015). The EU Mission Starfish emphasizes the importance of protecting the oceans and water systems as these are fundamental for life on Earth. Ecosystem services and resources in and of water, and the possibilities of "[…]

leisure, well-being and growing economy is presented as reasons for protection and restoring. At the same time, the strategy report also mentions the importance of oceans and waters for "[…] culture, identity and sense of belonging", and that the value of the oceans and waters as common good overrules their economic value. The benefits are first and foremost related to ecology, society and culture (European Commission et al., 2020). The Sámi Parliament Statement on Area reflect on how to understand sustainability by stating that traditional use of resources has been "[…] in balance with available resources and area" (our translation), with respect to future generations possibilities and at the same time be able to utilize nature to make a living and feed yourself, to get by, the concept of *birgejupmi* (Sámi Parliament, 2016). This indicates that a focus on environment and society should be of main prioritation, and that preserving nature for future use is important. We find the similar descriptions in the Sámi Parliament Statement on Salmon (Sámi Parliament, 2021).

The BFA policyreport ((BFA, 2021) suggested that focusing on blue foods "[…] could also reduce the pressure on Earths resources" even though "Simply increasing the production of blue foods is not the solution […]". The topic resilience in food production systems is emphasised by the Farm to Fork Strategy (EC, 2020), the action plan Food, Humans and Environment (The Norwegian Governmental Ministries, 2019) and the BFA policy strategy . This is related to topics ecology and resilience in food production systems and respective control questions in Table 4. However, are the SDGs possible to combine with a focus on the biosphere? The goals are formulated in anthropocentric terms, and e.g., neglects animals (Torpman and Röcklinsberg, 2021). This deficit of the goals when implemented in a biosphere-directed framework should be taken into consideration, but it is already handled by the Wedding Cake Model where the biosphere is the foundation for, but not independent of, both the society and the economy (Rockström and Sukhdev, 2016). This structure has also been used for the design of our sustainability assessment (Table 4).

4.2. Stakeholder and citizen interviews

4.2.1. Concerns for ecology and environment

As stated above, the data from the documents indicate that a biosphere-focused framework is crucial. This view is also well represented amongst the stakeholders and in the citizen groups. One of the main concerns in the interviews with stakeholders are the possible negative impacts on nature and/or wild relatives of the farmed salmon, as well as on how to handle unknown consequences. Ecology-related concerns were expressed by scientists and fish health workers, participants from trade unions, salmon farmers, non-governmental organizations (NGOs), wild salmon management, Sámi resource management, and in Norwegian and Sámi citizen groups (see Table 4). To avoid negative impact on wild relatives and/or the environment by using genome-edited salmon is therefore crucial. The protection of and respect for nature was also used to describe sustainability amongst the stakeholders and citizens (wild salmon management, Sámi resource management, citizen group Norwegian, citizen group Sámi), and adding to this both participants from wild salmon management and salmon farming emphasised how food production and development which is sustainable must be performed "[…] on nature's own premises" (participant from wild salmon management, our translation).

Recently, a sterile salmon has been developed using genome editing and results shows it could be possible to produce brood stocks which are able to have sterile offspring (Güralp et al., 2020). This solution is presented as contributing to reducing the interbreeding between farmed and wild salmon when the farmed salmon escapes. This was shared to the participants in the interviews as one of several applications of genome editing pursued in salmon. Several stakeholders, including wild salmon management and NGO representants pointed to how interbreeding and genetic contamination is not the only problem related to escapees. They argued that the sterile salmon would still escape and

Table 4
Levels are from the rearrangement of the UN SDGs by Rockström and Sukhdev (2016) based on Agenda 2030 (UN, 2015).

Level UN SDGs	*Topics* Control questions
Biosphere 6: Clean water and sanitation 13: Climate action 14: Life below water 15: Life on land	*Ecology* • Does the alteration lead to increased protection/ conservation of biodiversity and/or ecosystems? (BFA, Starfish, FF, NGO, CGN) • Will application effect ecosystem functions? (FHE) • Will application impact wild fisheries or other species, reducing diversity and the use of more "regenerative and equitable practices"? (BFA, Starfish) • Will application of GE technology increase farming activity/intensity at the expense of wild species? (SPS) • Does the alteration lead to reproductive and non-reproductive impact on wild relatives? Reduce genetic variation in wild relatives? (NGAS, BFA, SGE, TUR, SAF, FHW, NGO, SRM, WSM, CGN) • What measures are taken to reduce interaction with wild relatives? (SGE, SRM, WSM) • How will GE technology affect the existing threats/interactions of the fish (e.g., Salmon: predators, escaped farmed salmon, climate change, pink salmon, other pelagic species (competition, predation), habitat destruction? (SPS) *Impact on environmental pollution (chemicals/ pharmaceuticals)* • Risk of selecting for novel pathogens or parasites? (FHW) • Is the use of medical treatments reduced? (SGE) • Does application reduce use of antimicrobials? (FF) • Will the use cause increased pollution? (BFA, NI, SGE,) • Does the new organism require new feed type, and is this feed more, less or equally impacting environment? (NGAS) *Climate change* • Are effects within the planetary boundaries? (NGAS, NI, BFA) • Are there negative impacts on the local/global environment? (SGE, SAF, FHW, TUR, WSM) • Will application improve climate change adaptability of the product/production/supply chain? (FHE, BFA, SPA, CGS) • Will application cause a shift in the distribution and productivity of species as a result of ocean warming and deoxygenation affect pelagic fisheries? (BFA) • Will use contribute to reducing greenhouse gas emissions? (BFA) • Contribute to climate action? (BFA) • Is environmental footprint changed? (FHE, BFA) *Resilience in food production systems* • Does the alteration lead to a production which is more diverse, resilient? (BFA, FF) • Will application increase (biological) diversity in global food production? (FHE) • Will application affect the genetic diversity in the eggs? (FHE)
Society 1: No poverty 2: Zero hunger 3: Good health and well-being	*Food safety, security and quality* • Improved food safety? (NGAS) • Improved global food security? (NI, NGAS, FHE)

(*continued on next page*)

Table 4 (*continued*)

Level UN SDGs	*Topics* Control questions
4: Quality education 5: Gender equality 7: Affordable and clean energy 11: Sustainable cities and communities 16: Peace, justice and institutions	• Does the alteration lead to a production of healthier products? (BFA, FHE)
	Justice and equal access
	• Does the alteration lead to production which is more just? (BFA) • Does application affect the product availability for poorer countries/groups in society, or more affordable? (FHE, ABR, CGS) • Does application of GE organism lead to centralization or spread of ownership? (NGAS) • Are there benefits except economic return? (BFA, Starfish)
	Future generations access to resources
	• Will the use of GE technology enhance future generations access to wild resources a) in traditional management? (SPS, SPA, TUR), or b) to indigenous cultural nature management? (SPA)
	Consumer and citizen engagement and acceptance
	• Is there broad public support? (Starfish, TUR, SRM, SAF) • How will the alteration be communicated to (end) consumer? (SAF, SGE) • Have relevant local communities, or groups with activities in the planned release area been consulted? (SPA, SPS) • Will application of GE technology enhance existing conflicts of interests/have negative impact on local harvesting activities? (SPS, WSM)
	Local and indigenous knowledge, rights and traditions
	• How does the alteration affect small-scale actors, local community and indigenous traditional fishing [possibility to choose another production method in the future, monoculture, impact on area competition]? (BFA, SPA, SPS, Starfish, SRM) • What is the cultural role of wild relative species? (SRM) • Have the Sámi society (if relevant in the area of application) been consulted? (SPS) • Have traditional knowledge been included in the assessment of possible effects on surrounding environment/society? (SPS) • Can indigenous and local knowledge, innovation and practice be preserved and respected by the introduction of the new organism? (SPS, SPA**)
	Gender equality in food production
	• Will application improve acknowledgement, rights, and positions of women in food production? (FHE)
	Global effects
	• What are the possible effects in other countries than Norway? (FHE) • Effects on small-scale farmers and fishers in least developed countries? (FHE)
Economy 8: Decent work and economic growth 9: Industry, innovation, and infrastructure 10: Reduced inequalities 11: Responsible consumption and production	*Farmed fish health, welfare and intrinsic value*
	• Does the alteration lead to improved animal welfare? (NGAS, FHE, FF, SGE, TUR, SAF, FHW, ABR, WSM, CGN, CGS) • What are specific fish health implications? (FHW) • Does the alteration allow for not improving negative conditions in environment? (NGO) • Does the alteration restrain the fish from outliving natural behaviour? (NGO, CGN) • Does the alteration cross species boundaries? (FHW, TUR, SGE) • Is the alteration respecting what changes are already happening in nature? (SGE, FHW) • Is the alteration infringing the intrinsic value of the fish? (CGN, SAF, SGE, WSM)
	Production efficiency
	• Is production made more efficient? (NI, TUR, SAF, ABR) o Preservation methods of product? (FHE) o Is food waste reduced? (FHE) o Costs reduced? (SAF) • Affect marked access of related products? (NGAS) • Does the production cause increased monoculture, and then possibly reduced resilience? (SGE, FHW, NGO, SAF, CGS)
	Available alternatives
	• Is the alteration preventative regarding specific challenges? (NI) • What are alternative solutions to the challenge the GE technology is meant to solve? (SPS) • What are consequences of not applying the technology? (SPS (if one technique is banned, will another be used?)
	Employment and economic growth
	• Does the use of GE organisms cause an increase in employment? (FHE) • Create livelihoods? (BFA)

Abbreviations: GMO (genetically modified organism), SGE (scientist using GE in fish), TUR (trade union participants), SAF (salmon farmers), FHW (fish health workers), NGO (non-governmental participants), ABR (advisory body participant), SRM (Sami resource management), WSM (wild salmon management), CGN (citizen group Norwegian), CGS (citizen group Sámi), NGAS (Norwegian Governmental Aquaculture Strategy), SPA (Sami Parliament area strategy), BFA (Blue Food Assessment), FHE (Food, Humans and Environment), FF (Farm to Fork), SPS (*Sámi Parliament Statement on Salmon*), NI (Federation of Norwegian Industries), **from the Convention on Biodiversity article 8j.

have non-reproductive effects. Bradbury et al. (2020) has also pointed out this concern; an escaped farmed salmon will compete for resources and disturb the mating season. One of the trade union participants mentioned that this ecological impact is relevant as Norway holds 25% of the global salmon stock. After the conduction of the interviews the salmon stock in Norway has gone from being viable to near threatened and is on the Red List (Hesthagen et al., 2021). The main impact factor is human activity, including genetic contamination from escaped farmed salmon and spread of diseases (Thorstad et al., 2021). To preserve the wild salmon stock is therefore essential and implies that one should avoid escapes by salmon in general including the genome-edited salmon that is sterile. One solution to this may be, as suggested by a researcher and in the Norwegian citizen group, to only allow genome-edited salmon in land-based facilities.

4.2.2. Concerns for increasing farming activity

Some participants (scientists, citizen group Norwegians) mentioned terms like self-maintainaing, on-going, self-fuelling, durability and so on, when defining sustainable development. This way of describing sustainability requires that utilization of natural resources do not exceed more than we need, and associates to terms historically used to describe the relation between humans and nature which we today define as sustainable development (Du Pisani, 2006). Further, it indicates a fear of industries, like the salmon farming industry, to grow beyond planetary boundaries. A general concern amongst several of the stakeholders and the citizens (see Table 4) was whether genome-edited salmon would legitimize increased growth in the industry. One of the salmon farming participants expressed it as a risk of creating "[…] an evil circle" (our translation) as symptoms of a problem in the industry is removed, it will allow to increase the production. At present salmon farming in Norway is mainly monocultures, thus increasing the production intensity will lead to the bloom of new, and possibly unknown diseases (Grefsrud et al., 2022), hence solutions provided by genome editing can be considered only as short term solutions if not combined with mechanical solutions and systems changes.

In the Sámi citizen group, this was pointed out by that "[…] nature is long-term, economy is short-term" (our translation). This is an argument which is based on a general critique against aquaculture or a scepsis towards industries driven by profit, it is independent of genome editing, but more directed to the system it is going to be used in. But it also gives some directions for how to solve present challenges. In a recent article by Rosendal and Olesen (2022) discussing the lice problem, they ask why there is so little attention to strategies that promote public good, as for example breeding strategies including the use of genome editing. They point out that the main focus on the problem has been on innovation in novel ways of treatments by chemicals or mechanical devices, increasing pollution and decreasing animal welfare. This illustrate that the industry needs to take a more systematic long-term approach and consider sustainability through its own activities as well as effects on the surrounding environments. Introduction of new farming activities or the use of genome editing may in such a context need to *consider whether the change creates positive effects, not only avoid or reduce present negative effects. In the conversations with stakeholders and citizens, positive contributions to human health, fish welfare and reduced environmental impact is crucial for acceptance of genome editing, as stated in a Norwegian citizen group:* "It should be good for all involved" (our translation).

Looking at the publications by BFA it is evident that the farmed salmon can contribute to, but is not as a crucial product in, global food systems (BFA, 2021). The work shows the importance of several other aquatic animal groups and of combining groups in the diet to ensure diversity of nutritional intake (Golden et al., 2021). This indicates that using genome editing in aquaculture should be combined with farming and aquaculture practises that contribute to increasing the diversity in species. Second, the importance of small-scale actors, including indigenous groups, in both farming and fisheries should be acknowledged, as diversity is "[…] key to the future of aquatic food systems" (Short et al., 2021).

4.3. Local and indigenous knowledge, rights, and traditions

The Norwegian governmental and the Sámi Parliament documents do all have a long-term focus, and aims at ensuring future generations access to resources, but the means on how to achieve such development is different in the context of how to utilize the oceans and waters. Sustainability in the strategy by the Ministry of Trade, Industry and Fisheries (2021) is described as "[…] the world becomes a better place for the humans living now, without compromising the possibilities of future generations" (our translation). The Sámi Parliament Statement on Salmon builds on politics grounded in values of "respect for, knowledge about and connectedness (*nærhet*) to nature" and "The management of resources is done in a long-term perspective focusing on future generations possibilities" (Sámi Parliament, 2021), our translation).The concepts of reciprocity, care and connectedness to nature is according to Mazzocchi (2020), found in general in relation to indigenous knowledge.

The Norwegian governmental aquaculture strategy states that environmental impacts from aquaculture must be reduced as much as possible, and Norwegian seafood [farming of salmon] is an important part of global food security (Ministry of Trade, Industry and Fisheries, 2021). The Sámi Parliament Statement on Salmon emphasizes that aquaculture cannot exist at the expense of wild salmon fisheries, but the situation today is that farming of salmon is threatening the wild salmon stocks (Thorstad et al., 2021) and thus Sámi traditional harvesting (Sámi Parliament, 2021). This conflict is also described in the Sámi Parliament Statement on Area (2016) with regards to how withdrawal of access to nature area conflict with Sámi traditional use of local nature. This management is based on that "[…] anyone who uses nature (*utmark*) have to be aware of their responsibility for preserving nature for future generations" (Sámi Parliament, 2016, our translation). Both Sámi Parliament statements also emphasize the lack of including traditional knowledge in Norwegian Governmental management strategies, and this conflict is also described by e.g., Joks and Law (2017). Traditional knowledge should be used in evaluations of natural resources in addition to scientific knowledge because it is an expression of the experience of generations, which is required in the Convention of Biological Diversity article 8j (CBD, 1992) and demanded by law in the Norwegian Nature Diversity Act of 2009 (Ministry of Climate and Environment, 2009). Impact on indigenous and local people's culture and traditions by the use of gene technology, is however only included in the final ethical assessment checklist under the GTA (Ministry of Climate and Environment, 2005). An improvement would be to include indigenous views and knowledge of natural resources into a sustainability assessment too.

In the Sámi citizen group, sustainability was perceived in different ways. One of the participants said that "Sustainable development now, in an industrial society, is more about not using too much of the earth resources. But when I think about original Sámi sustainable development, that is about it staying, right, that the highlands and the forest shall remain as it is […], it is about not disturbing nature" (our translation). Another participant answered that "[…] we cannot live as our ancestors did, so now it is about reducing the footprint, because we leave footprints, that's just how it is, but [we need to] be aware of how to reduce the footprint, and [prioritize what footprint to make]" (our translation).

Empowering indigenous groups is included as one of the actions suggested by the Blue Food Assessment policy strategy (BFA, 2021). Including and applying Sámi resource management could be of great advantage as an important concept in Sámi resource management is expressed in the word *birgejupmi* – to get by (*å greie seg*) (Sámi Parliament, 2016). The concept aligns with the concept of planetary boundaries – both are about how humans should get by within the capacity of nature. The conflict between Sámi nature management and salmon farming was also emphasised by one of the wild salmon management participants in interview. S/he explained the term *birgejupmi* by how the farming industry is expanding at the expense of wild fish stocks, and this reduced the ability of the wild fish to also get by. This is associated to thinking about sustainability where the biosphere is prioritized and respecting the planetary boundaries is the main way to achieve a sustainable development.

4.4. Animal welfare as part of sustainability

The previous published reports and articles on sustainability assessment of GM plants include animal welfare in terms of impacts on animals by GM plant-based feed (see Table 1). Regarding a genome-edited salmon or fish, it must be re-assessed in terms of how to include animal welfare in the assessment. Looking at the interviews, we see that most participants expressed a concern for the welfare and health of fish (see Table 4), and for several, this should be of main priority when considering using genome editing or not. Both in terms of not enhancing negative welfare impacts already present in the farming of fish, and second to consider applications of genome editing which would improve welfare directly. Some also included animal welfare when defining what sustainable development is (NGO participant, wild salmon management, scientist, fish health worker and in the Norwegian citizen group). The importance of welfare of fish has also recently been emphasised both in the European Commission communication "Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030" (2021) and in the "European Group on Ethics in Science and New Technologies opinion on the Ethics of Genome Editing" (EC, 2021). We have placed this topic under pillar economy as it includes the SDG 12: *Responsible* production and consumption.

Welfare is connected to sustainability by two routes. First, bad welfare will impair on the production, as pointed out by most of the stakeholders and citizens when talking about animal welfare. Second, an animal welfare NGO and a representant from fish health research (designated to group fish health workers) emphasised how bad welfare is not sustainable *in itself*. This has also been stated by Broom (2010), and we have discussed this connection in a previous book chapter (Blix and Myhr, 2021). When sustainability is defined as something that should be possible to continue doing for a long time (definition also used by stakeholders from e.g., research on genome editing, environmental NGO, wild salmon management), unethical treatment of animals cannot be accepted in what is to be a sustainable production. Animal welfare indicators are also the most used indicators in global certification standards, as shown by Amundsen and Osmundsen (2018), and recently included in an animal protein production sustainability assessment framework by Broom (2021).

Originally, the sustainability guideline document by the NBAB (2009) claimed that the intrinsic value for nature should be included in an ethics assessment, not sustainability. In Norway, the farmed salmon is protected by the Animal Welfare Act (Ministry of Agriculture and Food, 2009) which states that all animals have intrinsic value. Operationalising this in a sustainability assessment could be supported by the Sámi Parliament statement on area stating that nature and all living in it should be respected as part of a sustainable management. The importance of intrinsic value of fish was also raised in stakeholder groups of salmon farmers, scientists, wild salmon management, citizen group Norwegian, and citizen group Sámi. How this could be operationalized is discussed by Trøite and Myskja (2021) stating that including intrinsic value of salmon in farming would require either to abolish the whole industry or to make sure the production is adapted to species-specific behaviour of salmon. Whether genome editing can be used to promote the latter solution, should be further discussed, and was also brought up in the Norwegian citizen group by one of the participants stating that sterility would not be part of respecting natural behaviour of the salmon.

5. Conclusion

In this work we have used global and Norwegian strategy documents for sustainability, and interviews with stakeholders of salmon farming industry and citizen groups to generate a sustainability assessment framework for genome-edited salmon. Table 4 presents the final topics and control questions identified in documents and interviews. Topics to be included in a sustainability assessment of genome-edited salmon are:

- Biosphere: ecology, impact on environmental pollution, climate change, and resilience in food production systems,
- Society: Food safety, security and quality, Justice and equal access, Future generation access to resources, Consumer and citizen engagement and acceptance, Local and indigenous knowledge, rights and traditions, Gender equality, and Global effects,
- Economy: Farmed fish health, welfare and intrinsic value, Production efficiency, Available alternatives, and Employment and economic growth.

For all topics, both local and global impacts should be considered when relevant, and long-term effects must be included. We urge the need to focus these assessments of impacts on the biosphere as a main prioritization as this creates the foundation for sustainable society and economy, both in short, but especially in the long-term and on both local and global level. Our findings indicate that discussing sustainability assessment through the lense of resilience would be an appropriate next step as it could contribute to the development of more sustainable fish farming and food production systems. It would also be valuable to apply the suggested framework on specific cases of genome-edited salmon or other finfish species to identify any challenges and/or missing topics and control questions.

The main result is that approval of a genome-edited organism should be based on questions that gives information on whether the commercialisation could enhance, preserve, or at least not have a negative impact on the resilience in the ecosystem where it is to be released in or can escape to. This is reflected in documents analysed and interviews held as they focus on environment, ecology and climate. We also find it in how documents, stakeholders and citizens define sustainability, where descriptions often return to how the Earth is the main foundation and should be protected and respected. As argued by Amundsen (2022), the understanding and implementation of sustainability is limited to the questions asked in the assessment. This is also the limitation of this framework. However, by grounding the whole framework in the Wedding Cake Model (Rockström and Sukhdev, 2016) and prioritizing the planetary boundaries and on *what creates resilience* we aim at giving the framework a consistent basis for how to understand sustainability, which aligns with the documents and stakeholder and citizen views. The discussion could be continued in a study of how resilience can be a key for the assessment of genome-edited salmon.

Second, the framework should include the topic *Local and indigenous knowledge, rights, and traditions.* In an indigenous understanding of sustainable development, in this case the Sámi understanding, it builds on generations of experience utilizing nature with the intention of ensuring resources of future generations. This can be associated to how respecting the planetary boundaries is the main way to achieve a sustainable development. In addition, some wild species like the salmon are highly significant to the preservation and development of indigenous and local cultures, and in some cases crucial for survival. Indigenous and local knowledge, rights and traditions should therefore be considered in a sustainability assessment of genome-edited fish.

Third, animal welfare should be included in the sustainability assessment because good animal welfare is important for an efficient production and because a system cannot be sustainable if it contributes to animal suffering and thus a more evil society – it cannot be accepted (Olesen et al., 2011), not in short nor in the long term.

Finally, we want to emphasize that this framework aims to contribute to building resilient and diverse food systems, terms often used in the strategy documents. Both resilience and sustainability build on the idea of ensuring the best conditions for humans and environment, under "[…] normal and extreme operating conditions" (Marchese et al., 2018). This framework should be further developed to provide an assessment which is flexible with regards to the control questions used to make case-by-case decisions, but also focused and specific to ensure all assessments are done with the aim of ensuring that genome edited fish contribute to building resilient and diverse food systems.

Ethical considerations

The interviews conducted for data sampling to this paper has been submitted to the Norwegian Centre for Research Data (NSD), reference number 707095. NSD approved the interview guide, the plan for recruiting participant groups including citizens, and data management plan. All participants to in-depth interviews signed declaration of consent for the use of data generated in the conversation. Participants in group interviews were recruited by IPSOS AS and have signed a standard declaration about GDPR and how data is stored generated by IPSOS AS. All participants are de-personified in the analysis of the data as some information about their occupations could indicate individual people. Most participants involved will not be identifiable based on occupation (in-depth interviews) and are therefore considered anonymous. Data are not openly available outside the project group.

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CRediT authorship contribution statement

Torill B. Blix: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Anne I. Myhr:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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