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ORIGINAL ARTICLE

Exploring solutions for healthy, safe, and sustainable fatty acids (EPA and DHA) consumption in The Netherlands

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Abstract

Advisory bodies such as the World Health Organization and the Dutch Health Council (DHC) recommend including fatty fish in one's diet, based on the health benefits of their content of $n-3$ poly unsaturated fatty acids (eicosapentaenoic acid—EPA and docosahexaenoic acid—DHA) being, i.e., the reduction of the risk of fatal cardio vascular disease and stroke. These dietary advices on these fatty acids' (e.g., fatty fish) consumption are only based on the expected health benefits. But what would a dietary advice look like when the health benefits were weighed up against relevant sustainability and food safety considerations? The aim of the current study was to explore the consequences for safety, health, and sustainability of solutions to meet the DHC's recommendation on EPA/DHA consumption. To this end, first, the health, food safety, and sustainability perspectives of the current fish production and consumption, being the main source of EPA/DHA, were identified. Second, alternative diet scenarios, meeting the daily advised intake of EPA/DHA, were collected and subsequently judged on their health, safety and (environmental) sustainability characteristics. To enable structuring the process of finding solutions for such complex problems, a specific framework was applied: solution-focused sustainability assessment. Based on stakeholder consultation, three scenarios were assessed: higher production and consumption of fatty fish (here: farmed salmon); increased human use of by-catch and discards; and increased consumption of alternative EPA/DHA sources (here: walnuts). It appeared that only in the scenario of increased use of by-catch and discards, the effects on human health and the environment and resources coincide, whereas in the other two scenarios, the positive health effects are expected to result in one or more negative effects on the environment. Besides, increased fish consumption causes more food safety problems; however, if one changes his/her diet and replaces meat by fish, this will lead to a net higher food safety. The analysis shows the sustainability limits of increased production and consumption of fatty fish and alternative EPA/DHA sources. This can support policy makers in setting goals and deciding on measures to encourage healthy and environmentally sustainable fish (i.e., EPA/DHA) consumption. Furthermore, this study shows in general the impact a policy initiative focusing on health aspects only can have on other aspects, such as environment and food safety. It emphasizes the added value of integrative assessments, which cover multiple effects when designing new sustainable policies.

Keywords Fish consumption · Fisheries · Fish farming · Health · Fatty acids · Food safety · Sustainability · Solution-focused risk assessment

Introduction

Public health advisory bodies such as the World Health Organization (WHO) and the Dutch Health Council (DHC) recommend including fish in one's diet, based on the health benefits. The large health benefits of fish rely mainly on their content of the so-called $n-3$ polyunsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DPA). Eating fish once a week decreases the risk of fatal cardiovascular disease (CVD) by 15% and the risk of

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stroke by 10% and increases intelligence quotient (IQ) points in offspring due to an increased consumption of EPA/DHA (Gezondheidsraad 2015). Therefore, the DHC recommends consumption of one portion (100 g) of preferably fatty fish per week, which roughly corresponds with an intake of 250 mg EPA/DHA per day. These recommendations are in line with those of other (inter)national authorities (e.g., Nordic Council, EFSA). This dietary advice of the DHC on fish consumption is based on the expected health effects only; other issues related to fish consumption, such as food safety and environmental sustainability, are not considered in the advice.

Within The Netherlands, about 65% of the population consumes fish at least once a week and 18% less than once a week. The remaining 17% consumes hardly any or no fish. A slight majority (53%) of the consumption originates from wild-caught fish and the rest from cultivated fish (Seves et al. 2015). On average, 65% of the EPA/DHA intake of the Dutch originates from fish. The average total intake of EPA/DHA in The Netherlands is 135 mg/day, 115 mg less than the Health Council's advice. One way to meet the EPA/DHA advice by the DHC in the Netherlands is to increase the consumption of fatty fish. But what would a health-based advice on fish consumption look like when the benefits are balanced against other relevant considerations? Would other EPA/DHA sources than fish be preferable? The trade-offs of the fish production and consumption system on health, safety, and environment are mentioned in the scientific literature, for example in Garnett (2013), but research on combining or comparing the different health and sustainability aspects and dealing with these trade-offs is scarce. A first attempt is provided by Seves et al. (2015) who compared the fatty acids content and CO_2 footprints of various fish species consumed in the Netherlands.

Fish is food with trade-offs between health, food safety, and environmental sustainability. As mentioned before, it is considered healthy. On the other hand, fish can be contaminated with toxic substances such as methyl-mercury (Risher et al. 2002) and dioxins (JECFA 2002) or with hazardous microorganisms, which both cause food safety issues. Several authors, e.g., Hoekstra et al. (2013) and FAO/WHO (2011), have investigated this risk-benefit assessment on effects on humans. Furthermore, there are several issues concerning the sustainability of fish consumption such as the use of resources and environmental pollution. Fisheries have intensified in the last decades, and problems arise from this intensification (e.g., Gordon et al. 2018; Jackson 2009; Naylor et al. 2000): many fish species are overfished, and the intensive fisheries disrupt marine and fresh water ecosystems, causing loss of biodiversity (e.g., Arthington et al. 2016; Trites 2003; Cury et al. 2003; Dayton et al. 1995). Fish farming systems change local coastlines and may emit antibiotics, pathogens, and eutrophying substances into the natural ecosystem (Gislason 2003). A thorough review on the different aspects of fish consumption in relation to both food safety issues and sustainability issues can be found in Additional file 1.

The aim of the current study was to explore the health, food safety, and sustainability aspects of solutions to fulfill the dietary need in EPA/DHA. To come to a comprehensive integrative assessment on sensible EPA/DHA consumption, various aspects that act on different dimensions and scales have to be addressed, which also may be hard to quantify and difficult to aggregate. Besides, many stakeholders and their different perspectives are involved in the production and consumption of fish. We followed the solution-focused sustainability assessment (SfSA) framework (Zijp et al. 2016) to make an integrated assessment with reliable solutions on the EPA/DHA consumption issue. We investigated the solutions that were brought forward by a group of stakeholders to fulfill the recommendations on EPA/DHA and assessed the health, safety, and environmental sustainability impacts of these solutions. As a benchmark, also the health, safety, and sustainability perspectives of the current EPA/DHA consumption were identified and described qualitatively and, if possible, quantitatively.

We are aware that also social, cultural, and economic aspects are important in food production and consumption systems. These were outside the scope of the current study. Nonetheless, the outcomes of this study form the first step from mono-disciplinary discussions on the benefits and drawbacks of fish consumptions to inter-disciplinary discussions on solutions for sustainable consumption.

Methods

The aim of the current study to explore the health, food safety, and environmental sustainability aspects of solutions to fulfill to dietary need in EPA/DHA was fulfilled by applying the SfSA framework (Zijp et al. 2016). The key elements in SfSA are the involvement of stakeholders from a very early stage of the process, and the fact that—open minded—potential solutions are formulated in the beginning, without directly thinking of limitations. In later stages, the solutions are specified in detail and the possibilities and limitations are assessed. After background information concerning the current EPA/DHA intake (mainly from fish), was collected, with its advantages and drawbacks (see Additional file 1), potential solution scenarios for increasing the EPA/DHA consumption in The Netherlands were defined in a brainstorm workshop with a group of stakeholders (see Additional file 2). The results of this stakeholder investigation were assembled and solutions were selected by the authors and stakeholders. Based on the options brought forward, we designed specific scenarios and quantified the required amounts of fish/other products, as well as the consequently required usage of resources and energy, on which we performed an integrated assessment. On each of the different areas of protection, the assessments were performed as quantitatively as possible.

Stakeholder consultation and selection of scenarios

In the stakeholder workshop, all participants discussed their perspective on the advantages and drawbacks of increased fish consumption in The Netherlands. Stakeholders from different disciplines were involved: human health, nutritional science and environmental science experts, non-governmental organizations (NGOs), microbiological and toxicological food safety experts, as well as fisheries. Together we formulated potential scenarios for sustainable EPA/DHA consumption. Three scenarios that might contribute to solving the perceived problem were finally chosen by the authors and stakeholders together. These were:

1. increased fish farming (in this case farmed salmon);
2. better use of by-catch and discards;
3. increased consumption of alternative protein and EPA/DHA sources (in this case walnuts).

The scenarios that were proposed by the stakeholder workshop were made specific to be able to assess their positive and negative effects. In each scenario, the recommended EPA/DHA intake of the DHC (250 mg EPA/DHA per day) was translated into actual dietary advices for fish (scenario 1 and 2) or for walnuts (scenario 3) to be consumed. Subsequently, each scenario was compared with the reference scenario, reflecting the current fish consumption in The Netherlands. In "Design of quantified scenarios" section, we describe the four scenarios.

The EPA/DHA content in different foods

To be able to quantify specific scenarios on EPA/DHA consumption, knowledge about its content in different food products was needed. The EPA/DHA content in fish varies according to fish species, size, season, and the composition of feed (Murray and Burt 2001). Fatty fish species, such as salmon, mackerel, and herring, contain a high amount of fat and EPA/DHA. The EPA/DHA content of cultivated fish depends largely on the fish feed composition (Harlioğlu et al. 2012; Sérot et al. 1998; Zakerim 2011). Therefore, we fitted the amount of EPA/DHA in farmed salmon based on the EPA/DHA contents of the other sources (NEVO 2018) and the total daily Dutch intake of 135 mg EPA/DHA. From the species we evaluated, the average reported EPA/DHA contents are given in Table 1. For comparison, the content in cod (a non-fatty fish) is provided as well. One could use alternative sources of EPA/DHA for human consumption, for instance microalgae (the initial EPA/DHA producers in the food chain). In The Netherlands, applications of algae already exist in infant milk, supplements (oil capsules), and pharmaceuticals (Adarme-Vega et al. 2012). Also, transgenic plants, seaweed, and krill oil can be sources of EPA/DHA (Adarme-Vega et al. 2014; Nichols et al. 2010). In addition, some foods that are already part of the common Dutch diet contain EPA/DHA, for example, walnuts and almonds. The average EPA/DHA contents of these alternative sources are also given in Table 1.

Design of quantified scenarios

Impacts on the three main issues were covered in the assessment: human health, food safety, and sustainability (use of resources, environmental health), subdivided in a number of subthemes (see Table 2). In Fig. 1, a flow diagram of the EPA/DHA production and consumption system in The Netherlands is given, in which the orange boxes indicate the possible effects on human health, food safety, and sustainability. Blue boxes indicate the different EPA/

Table 1 Average EPA/DHA contents of most commonly consumed fatty fishes in The Netherlands (NEVO 2018) and of alternative EPA/DHA sources

Source	EPA/DHA content (mg/100 g whole fish)
Wild salmon	1803[a]
Farmed salmon	4140
Herring	1172[a]
Mackerel	3946[a]
Cod	405[a]
By-catch	1841[c]
Fish oil capsules	2500[a]
Walnuts	204[a]
Almonds	56[a]
Egg	35[a]
Poultry	0[a]
Beef	0[a]
Pork	0[a]
Algae oil	2500[b]
Seaweed (raw)	4–186 mg[b]

[a]NEVO: http://www.rivm.nl/en/Topics/D/Dutch_Food_Composition_Database/nevo-online.rivm.nl, visited on January 30, 2018

[b]http://ajcn.nutrition.org/content/83/6/S1526.full.pdf+html

[c]Average of mackerel, cod and herring

Table 2 The areas of protection, the themes, and the indicators that were used to assess the sustainability aspects covered in this study

Area of protection	Theme	Indicator/unit
Human health	Human health benefits	DALY
Food safety	Toxicological safety	DALY
	Microbiological safety	DALY
Sustainability: resources	Fossil fuel use	kg oil-eq
	Land	m^2 land area used
	Water	m^3 water used
	Fish stocks	+/0/−
Sustainability: environmental health	Climate change	CO_2-eq[a]
	Chemical pollution	+/0/−
	Eutrophication	N-eq[b]
	Disruption of local ecosystems	+/0/−[c]

[a] kg CO_2-eq refers to the amount of greenhouse gasses emitted, recalculated by impact rates to CO_2-equivalents using the ReCiPe LCIA method (Huijbregts et al. 2017)

[b] kg N-eq refers to the amount of nitrogen containing substances emitted (e.g., dissolved and inorganic), recalculated by eutrophication impact rates to nitrogen equivalents using the ReCiPe LCIA method (Huijbregts et al. 2017)

[c] Local ecosystem quality refers to biodiversity effects due to fishery activities, and disruption of bottoms and coastlines

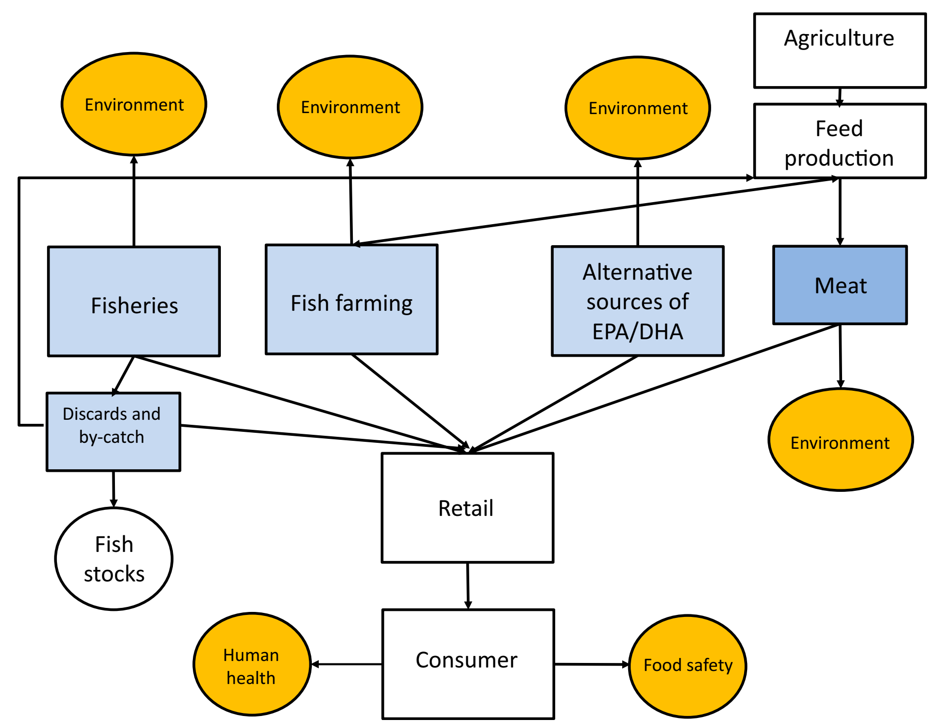

Fig. 1 Flow diagram representing the current EPA/DHA production and consumption system in The Netherlands. Blue boxes indicate the different EPA/DHA sources; orange boxes indicate the possible effects on human health, food safety and the environment. Meat is included in the diagram, since it currently is a major source of EPA/DHA in the Dutch diet (and since in the alternative scenario given in the Discussion section fish consumption partly replaces meat consumption)

DHA sources. Meat is included in the diagram, since in the alternative scenario given in Discussion section fish consumption partly replaces meat consumption.

Existing scenario: current intake

In Table 3, the average Dutch daily intake of EPA/DHA from the different sources is given. The current daily intake of EPA/DHA in The Netherlands is 135 mg, of which over 90% (123.7 mg) originates from the consumption of fatty fish. This equals 4.8 g of mainly herring, mackerel, and salmon per day (34 g per week). The remaining 10% (= 11.3 mg/day) is contributed mostly to by eggs and nuts/seeds. An extra daily intake of 115 mg/day EPA/DHA can be achieved by an increased consumption of farmed salmon (scenario 1), or of fish by-catch and discards (scenario

Table 3 Overview of the Dutch consumption EPA/DHA in the different food products in The Netherlands for the reference situation and for the three solution scenario's in mg/day, thereby assuming that increased fish consumption does not replace meat consumption

Amount per person [EPA/DHA mg/day] (food item g/day)	Scenario 0 Reference scenario	Scenario 1 Increased fish farming	Scenario 2 Increased by-catch and discards	Scenario 3 Increased walnuts
Wild salmon	16.2 (0.9)	16.2 (0.9)	16.2 (0.9)	16.2 (0.9)
Farmed salmon	74.5 (1.8)	<u>**189.6 (4.6)**</u>	74.5 (1.8)	74.5 (1.8)
Herring	21.1 (1.8)	21.1 (1.8)	21.1 (1.8)	21.1 (1.8)
Mackerel	11.8 (0.3)	11.8 (0.3)	11.8 (0.3)	11.8 (0.3)
Cod	–	–	–	–
By-catch and discards	0.0 (0)	0.0 (0)	<u>**115.0 (6.2)**</u>	0.0 (0)
Fish oil capsules	–	–	–	–
Walnuts	0.8 (0.4)	0.8 (0.4)	0.8 (0.4)	<u>**115.8 (56.8)**</u>
Almonds	–	–	–	–
Egg	10.5 (30)	10.5 (30)	10.5 (30)	10.5 (30)
Poultry	0.0 (23.2)	0.0 (23.2)	0.0 (23.2)	0.0 (23.2)
Beef	0.0 (15.7)	0.0 (15.7)	0.0 (15.7)	0.0 (15.7)
Pork	0.0 (41.1)	0.0 (41.1)	0.0 (41.1)	0.0 (41.1)
Algae oil	–	–	–	–
Seaweed (raw)	–	–	–	–
Total EPA/DHA (mg/day)	135	250	250	250

In underlined bold the changes in the scenarios with respect to the reference scenario

Between brackets the total weight of the intake per product in g/day

2) or of alternative EPA/DHA sources, in this case walnuts (scenario 3). These dietary scenarios are also sketched in Table 3.

Scenario 1: Increased fish farming

In the first alternative scenario, adherence to the recommendation of the Dutch Health council is achieved by increasing the consumption of farmed salmon. Salmon, especially farmed salmon, is a fish species that is fatty, and popular in the Netherlands. If the Dutch were to increase their farmed salmon consumption to a level in line with the recommendation, it implies a two to threefold increase in consumption to roughly 3.5×10^5 ton/year. The edible part of a salmon is about 60% (Broekema 2015). In addition, there are about 10% losses through transport and decay at retailers and consumers. Hence, the production of farmed salmon needs to increase to about 5×10^5 ton/year to supply the Dutch population.

Scenario 2: Better use of by-catch and discards

By-catch is fish that is not the primary target species of a fishery, but has enough economic value to be landed and brought on the market. Discards are fishes that have too little economic value because of their size, shape or species, and are therefore discarded into the sea. Since 2015, fisheries are obliged to keep discards of quota species on board and to land them (https://ec.europa.eu/fisheries/cfp/fishing_rules/discards_en; visited on January 9th 2018). The pelagic species could in theory be used to increase the availability of EPA/DHA for humans. We assume that the fatty fish by-catch and discards have an EPA/DHA contents equal to the average of mackerel, cod and herring (1841 mg/100 g), since those are the most caught fish species in North-Western Europe. To obtain 250 mg/day of fatty acids per person from this source would require about 2.7×10^4 ton/year of used by-catch and discards.

Scenario 3: Alternative EPA/DHA sources (walnuts)

In this scenario, adherence to the recommendation of the Dutch Health council is achieved by increasing the consumption of EPA/DHA with 115 mg/day through the consumption of walnuts. Obviously, the non-fish intake of EPA/DHA could be realized by other innovative products such as algae or seaweed. Unfortunately, these products are not yet produced in large quantities and not part of the current average Dutch diet. Walnuts are a non-fish alternative that contains the highest concentration of EPA/DHA. Therefore, in this scenario walnuts were chosen as the alternative for fish. Walnuts contain 204 mg EPA/DHA per 100 g. So, an intake of almost 57 g of walnuts per day per person would be needed to achieve a daily intake of 250 mg EPA/DHA. This means a yearly extra production of 3.5×10^5 ton of walnuts. The worldwide production of walnuts in 2011 was 3.5×10^6 ton (FAO 2014), implying that in this scenario, the Dutch would consume 10% of the world production of walnuts or worldwide production needs to increase with 10%. An overview of the three scenarios on daily Dutch consumption of EPA/DHA is also given in Table 3.

Integrated assessment

The three scenarios described above were assessed on human health, food safety and environmental sustainability aspects as listed in Table 2, quantitatively when possible otherwise qualitatively. The spatial focus of the assessment was set on The Netherlands (Dutch fish consumption). But also production-related environmental impacts elsewhere, due to consumption of fish in the Netherlands, were incorporated in the assessment. The assessments were performed based on currently existing techniques and infrastructure as well as on the current demographic situation in The Netherlands. Another starting point of our analysis was that other countries remain at their current consumption levels. In other words, we assume no reduction of the Dutch export. For the two areas of protection 'resources' and 'environmental health', a life cycle perspective from cradle to grave was chosen. Thus, use of resources and the release of emissions during the life cycle stages of extraction, production, transport, consumption and disposal were taken into account. The assessment of impacts on human health focused on the consumption phase, so occupational health was not taken into account. Social and economic impacts were not addressed.

Calculation methods for the integrated assessment

Human health To calculate the health effects of increased fish consumption in the Netherlands, we used the QALIBRA tool (Hoekstra et al. 2013). This tool uses various input variables to compute health effects of fish intake and converts them into Disability Adjusted Life Years (DALYs). An increase in DALYs is evidence of a higher burden of disease whereas a decrease in DALYs implies a lower burden of disease. The DALY calculation consists of two components: the number of years someone suffers from a disease and the number of years someone loses due to premature death from the disease. Beneficial health effects associated with higher fish intake in QALIBRA are a reduction in fatal CVD and stroke and increase in IQ points in offspring due to an increased consumption of EPA/DHA.

The QALIBRA tool uses a population that is representative of the Dutch population and all intakes were set to 100 g per week per person, so individuals with lower consumptions were modeled to increase their consumption while individuals with currently higher intake were modeled to decrease their intake.

Food safety

Toxicological food safety

The QALIBRA tool was also used to calculate the DALYs associated with chemical contamination in fish. Negative health effects due to chemical contamination in fish comprise of lower IQ points in offspring due to higher methyl-mercury intake, lower sperm count in offspring, diffuse fatty change in the liver as well as lower productions of the thyroid hormone TT4 as a result of the dioxins present in fish (Zeilmaker et al. 2012; Van den Berg et al. 2006). In the model, each gram of fish intake is associated with 0.05 μg of methyl-mercury (Hoogenboom et al. 2003) and with 1.6 TEQ pg of dioxin and dioxin such as contaminants (De Mul et al. 2008; see also Additional file 1).

Microbiological food safety

The microbiological safety of food is reflected in estimates of the burden of food-related disease. The microbial food safety in the Netherlands is monitored through annual estimates produced by RIVM on the disease burden of 14 food-related pathogens in various food categories (Havelaar et al. 2012). The epidemiological estimates of the disease burden are expressed in DALY. The methodology for these estimates is described in detail in Havelaar et al. (2012). Based on Havelaar et al. (2008), the estimates are attributed to different food groups. To calculate the impact of the different scenarios, the disease burden attributed to a specific food group was divided by the daily consumption of that type of food, yielding the disease burden (DALY) per kilogram of consumed food (see also Additional file 1).

Resources and environment For the impacts on climate change (CO_2-eq emission), land use, water use, fossil fuel depletion, and marine eutrophication, a life cycle assessment (LCA) approach was applied. Thus, use of resources and emissions due to the life cycle stages: extraction, production, transport, consumption, and disposal were taken into account. Information on the different impacts per kilogram product were derived from De Valk et al. (2016) using the ReCiPe model (Huijbregts et al. 2017). These amounts were recalculated to the impacts for the total Dutch population per year.

For the impacts on local ecosystem quality, fish stocks and chemical pollution, quantitative data were not available. These impacts were judged qualitatively based on literature resources and expert judgment. Of the three scenarios, only scenario 1 was judged to have an extra effect on depleting fish stocks (fish farming uses wild fish for fish feed in some cases, e.g., salmon; Naylor et al. 1998). Local ecosystem quality was assessed to decrease in certain cases with increased fish farming in scenario 1 (e.g., loss of mangroves; Naylor et al. 2000). Ecosystems quality was assessed to be comparable to the reference in scenarios 2 and 3, since no justification could be given on the improvement neither on the degradation of ecosystems in these scenarios.

Results

The results for the three scenarios are summarized in Table 4 in absolute numbers, and relative differences between the three scenarios and the reference scenario are visualized in Fig. 2. In the figure, higher values indicate a higher (negative) environmental impact, whereas values below zero indicate of positive effect on the environment. The indicators that were assessed qualitatively were arbitrarily set to a value of 10 to give an indication of the positivity/negativity of the impacts with respect to the reference.

Table 4 shows that all three scenarios are estimated to have a positive effect on human health, winning more than 19500 DALYs for the total Dutch population with respect to the reference scenario, due to the health benefits attributed to the increased intake of EPA/DHA. Also, scenarios 1 and 2 show an increase in food safety problems, which leads to a loss of up to 3127 DALYs due to toxicological safety and a loss of up to 434 DALYs for microbiological safety.

Hence, in absolute terms, the human health benefits seem higher than the food safety risks in terms of DALYs. However, if we consider the relative benefits and drawbacks, the negative impacts due to food safety loss are (in %) higher than the wins (in %) on the aspects of human health (Fig. 2). More consumption requires more resources and comes with more emissions of greenhouse gasses, nutrients, et cetera. Of all solutions, scenario 2 (discards) shows the least trade-offs between the health benefits and impacts on resources and environmental health. Scenario 2 scores negative on all resource and environmental health indicators and, of all three scenarios, scenario 3 (walnuts) requires most land, water, and fossil fuel, and results in the most additional greenhouse gas emissions.

Table 4 Impact scores of the different scenarios with respect to human health, food safety, resource use, and environmental sustainability

Impact group	Impact	Unit	Reference scenario	Scenario 1: Increased fish farming	% (with respect to the reference scenario)	Scenario 2: Increased by-catch and discards	% (with respect to the reference scenario)	Scenario 3: Increased walnuts	% (with respect to the reference scenario)
Human health	Human health benefits	DALY	769818	750297	2.5%	750297	2.5%	750297	2.5%
Food safety	Toxicological safety	DALY	301341	304468	− 1.0%	304468	− 1.0%	301341	0%
	Microbiological safety	DALY	2516	2708	− 7.6%	2950	− 17%	2516	0%
Sustainability: resources	Fossil fuel depletion	kg oil-eq/year	7.6×10^8	8.1×10^8	− 6.9%	7.7×10^8	− 2.1%	9.4×10^8	− 24%
	Land use	m^2/year	5.0×10^9	5.2×10^9	− 3.6%	5.0×10^9	0%	6.6×10^9	− 31%
	Water use	m^3/year	6.1×10^7	6.2×10^7	− 2.7%	6.1×10^7	− 0.6%	6.0×10^8	− 94%
	Fish stocks	− /00/ ++	00	–	–	00	00	00	00
Sustainability: environmental health	Climate change	kg CO_2-eq/year	5.6×10^9	5.9×10^9	− 6.0%	5.6×10^9	− 1.4%	6.3×10^9	− 14.2%
	Chemical pollution	− /00/ ++	00	–	–	00	00	–	–
	Eutrophication (marine)	kg N-eq/ year	3.6×10^7	3.7×10^7	− 2.8%	3.7×10^7	− 0.4%	3.6×10^7	− 0%
	Local ecosystem quality	− /00/ ++	00	–	–	00	00	–	–

Absolute values are given per scenario as well as the relative differences between the scenarios and the reference (negative scores indicate a negative effect, i.e., an increase in DALY or an increase in resource use)

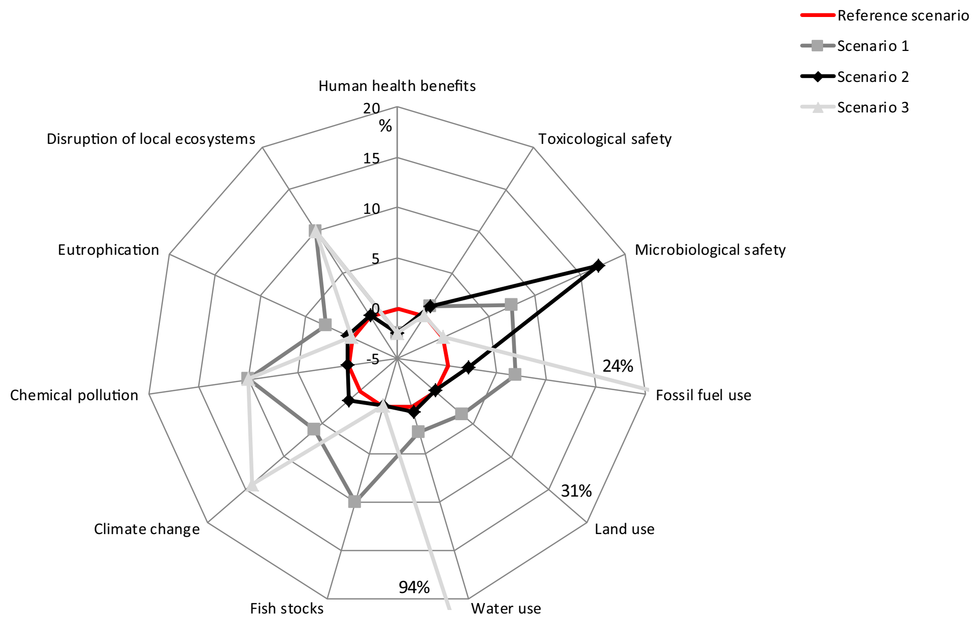

Fig. 2 Relative impact scores of the different scenarios with respect to human health, food safety, resource use, and environmental sustainability, compared to the reference scenario (in red). Indicators that were assessed qualitatively are arbitrarily set to a value of 10 to give an indication of the positivity/negativity of the impacts with respect to the reference

Discussion

Fish consumption is recommended by food authorities because of its health benefits for humans, but the results of this study show that these recommendations come with consequences for other aspects of the food-system, such as environmental health and resource availability. Furthermore, the exploration shows that a multiple disciplinary assessment in this field is possible and yields outcomes that provide insight in the trade-offs that should be taken into account in decision making. Here, we discuss the approach and the interpretation of the results.

First, the solutions discussed in this study are not the only three scenarios mentioned during the workshop with stakeholders. Other solutions were also mentioned, but focused more on changing the behavior of consumers by tempting them to eat more and other fish-products and less on alternative sources of EPA/DHA. Second, the exact definition of scenarios requires many choices. One choice with impact has to do with replacements. The analysis was performed by assuming that the consumption of foods to supplement on EPA/DHA adds to the present food consumption. However, in reality, extra fish (or alternative) consumption will usually replace the consumption of other foods. When assuming that fish consumption replaces meat consumption, the scores of the scenarios change significantly compared to the reference situation (Table 5 and Fig. 3). A gram for gram substitution was applied for scenario 1 (farmed salmon): a reduction of 2.8 g meat per day. In the other scenarios the same meat reduction was applied.

Table 5 and Fig. 3 show that if we assume that meat consumption is reduced with increased fish or walnuts consumption, the alternative scenarios will have more positive (or less negative) effects compared to the reference scenario, particularly on environmental health aspects (climate change and eutrophication) and resource use (fossil fuel use, water use, land use). The differences in results with Table 4 show the importance of clearly defining the solutions. A least for scenarios 1 and 2, there is a change in the trade-offs that are important for decision making, when replacement is included in the scenario's. On the other hand, the ranking of the scenarios does not change, which means that in both situations, with or without replacement, scenario 2 scores best and scenario 3 worst.

Thirdly, an important choice with impact on the results is that in this study, the scenarios mentioned by the stakeholders (and often heard in public discussions on this subject), were translated into figures, without considering the realism of the scenarios. For example, it was assumed that enough discards and by-catch are available for a 100% provision of additional EPA and DHA. In reality, however, Goudswaard (2015) estimated the discards of pelagic fish species from the Dutch fisheries to be about 1.0×10^4 ton/year. This is a rough estimation based on field observations. The Dutch discards can provide (in the best case) no more 37% of the required extra EPA/DHA. Therefore, the results could also be presented with less human health benefits in this scenario, which makes comparison between the scenario's even more interesting: scenarios 1 and 3 with more human health benefits, but also more environmental impacts and scenario 2 with less human health benefits but

Table 5 Impact scores of the different scenarios with respect to human health, food safety, resource use, and environmental sustainability if we assume that meat consumption is reduced in the scenarios with respect to the reference scenario

Impact group	Impact	Unit	Reference scenario	Scenario 1: Increased fish farming	% (with respect to the reference scenario)	Scenario 2: Increased by-catch and discards	% (with respect to the reference scenario)	Scenario 3: Increased walnuts	% (with respect to the reference scenario)
Human health	Human health benefits	DALY	769818	750297	2.5%	750297	2.5%	750297	2.5%
Food safety	Toxicological safety	DALY	301341	304468	− 1.0%	304468	− 1.0%	301341	0%
	Microbiological safety	DALY	2516	2640	− 4.9%	2882	− 15%	2449	2.7%
Sustainability: resources	Fossil fuel depletion	kg oil-eq/year	7.6×10^8	7.6×10^8	− 0.7%	7.3×10^8	4.1%	8.9×10^8	− 18%
	Land use	m^2/year	5.0×10^9	4.9×10^9	2.3%	4.7×10^9	5.9%	6.3×10^9	− 25%
	Water use	m^3/year	6.1×10^7	5.9×10^7	2.5%	5.8×10^7	4.6%	6.0×10^7	− 93%
	Fish stocks	− /00/ ++	00	–	–	00	00	00	00
Sustainability: environmental health	Climate change	kg CO_2-eq/year	5.6×10^9	5.6×10^9	− 0.04%	5.3×10^9	4.6%	6.0×10^9	− 8.2%
	Chemical pollution	− /00/ ++	00	–	–	00	00	–	–
	Eutrophication (marine)	kg N-eq/ year	3.6×10^7	3.5×10^7	4.0%	3.4×10^7	6.4%	3.4×10^7	6.7%
	Local ecosystem quality	− /00/ ++	00	–	–	00	00	00	00

Absolute values are given per scenario as well as the relative differences between the scenarios and the reference (negative scores indicate a negative effect, i.e., an increase in DALY or an increase in resource use)

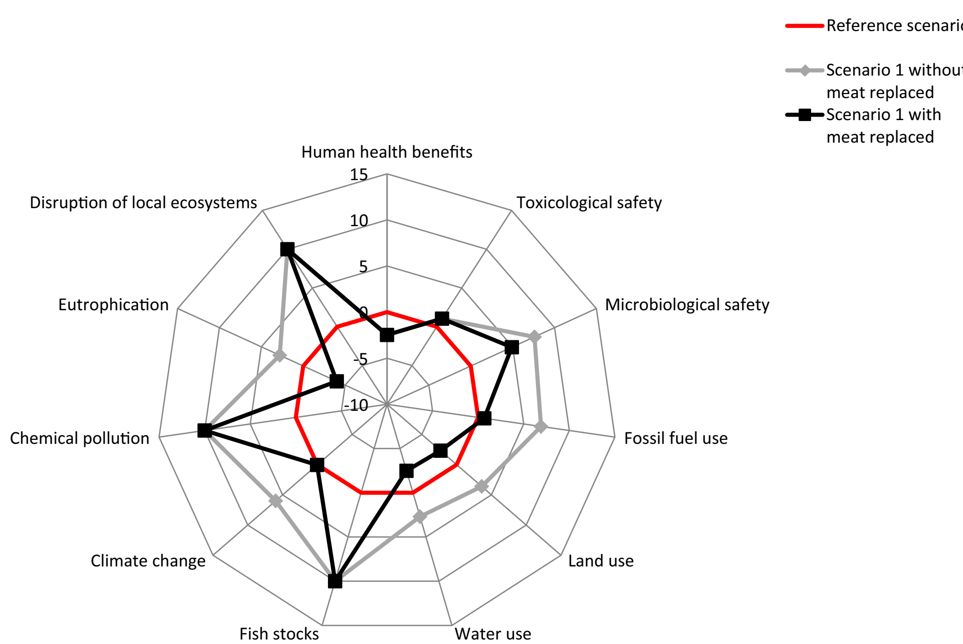

Fig. 3 Relative impact scores of scenario 1 with and without the assumption of reduced meat consumption with respect to human health, food safety, resource use, and environmental sustainability, and compared to the reference scenario (in red)

also less environmental impacts. Another example is scenario 3, in which the supplement of EPA/DHA was covered by extra walnut consumption. Walnut was chosen because it is, next to fish, the product with the highest EPA/DHA content known (Table 1). However, the amount of walnuts consumed as defined in scenario 3 is presently not realistic: i.e., such sudden shifts in diet as sketched in scenario 3 cannot be expected from the consumer. Also, 10% of the World's production of walnuts would in that case be supplied to the Netherlands, which is also not realistic.

Fourth, it was assumed that Dutch export of fish remains at the present levels in all scenarios. The Netherlands export large amounts of fish all over the world. A possible solution would be to reduce the export to supply the Dutch population with the recommended amount of fatty fish. However, less export means that the importing countries will have to find a different fish source: extra wild catch, extra aquaculture, or alternatives with similar environmental and food safety drawbacks as in the scenarios defined in this study.

Although the scenarios assessed in this study are not realistic, they are quantifications of solutions that are often mentioned in debates about fish consumption. As such they can be used in the debate on what is wise to aim for with respect to fish consumption, making the step from defining problems to defining solutions, and from problem focused sustainability assessment to solution focused sustainability assessment. The next step would be to discuss more realistic, nuanced policies and actions with stakeholders.

Conclusions

This study reveals trade-offs between human health, environment health, and safety of solutions for sustainable fish consumption. The approach followed can support policy makers in setting goals and deciding on measures to encourage healthy and environmentally sustainable fish/-food consumption. The exploration provides a first screening of solutions stakeholders think of and are often mentioned in public debates, but were not quantified before. Involving stakeholders is useful because their specific knowledge may result in solutions that are not considered by scientists and policy advisors. The next step is to discuss more realistic scenarios and accompanying policies with stakeholders and quantify those scenarios, with emphasis on the themes that show the highest divergence between them.

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