“Elaboration of Blue paper with principles”

Deliverable 6.2.3

In the context of the Project:

Ecological footprint in cross-border marine fish farming in Sagiada (Greece) and southern Albania (Acronym: ECO-FISH)

of the

Interreg IPA II Cross-Border Cooperation Programme Greece-Albania 2014-2020

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Preparation of this document

This document has been produced following Contract No. 1004 that has been signed on 12/03/2021, in the context of the project entitled: '*Ecological footprint in cross-border marine fish farming in Sagiada (Greece) and southern Albania*' with acronym ECO-FISH, under the "Interreg IPA II Cross-Border Cooperation Programme Greece-Albania 2014-2020". The project is co-funded by the European Union and by National Funds of Greece and Albania. The present deliverable is the product of collaboration between the team members of the Contractor that have implemented the deliverable also at the Programme eligible area (Thesprotia), in conformity with the restrictions due to COVID emergency.

Summary

The axes for Sustainable Aquaculture management cover both the aquaculture farms and their wider environments (such as production value chain, establishment sector, landscape, territory, region, country levels). The thematic modules focus on business management, site selection, risk assessment and their mitigation measures, operating systems' structure, engineering base or restoration, environmental impact management, farm operational dynamics, biosecurity and health management, market access, food safety, quality management, fish well-being, safe work of staff, and special business operations, including aquaculture-based fisheries, capture-based aquaculture, and high-seas aquaculture.

Sustainable aquaculture development has not been uniformed globally, and the sector has performed differently in different contexts, countries and regions. Some aquaculture development efforts have failed to promote socioeconomic and environmental progress, while other efforts have proven successful.

Extensive fish farming systems and integrated multi-trophic aquaculture systems (IMTA) managed, may effectively become much more than fish farm. This fish production operations may be managed to restore the damage produced in original wetland areas by former land-uses, minimizing its own ecological footprint and combining the economic benefits of aquaculture with objectives in conservation. However, the benefits that sustainable practices on extensive aquaculture and polyculture systems provide to wetlands, and the role of these activities on ecosystem restoration, are only known at a local scale.

The production of seafood from aquaculture is the fastest growing food production in the world and should be developed to be more environmentally sustainable. This is also the case for Albania which concerns the specific work and analysis. Several ways to reduce the impacts of existing or new aquaculture systems still exist, and key recommendations are recapped below based on the findings of the present study but also on results and analysis from other studies from the relevant literature.

Good aquaculture practices are a common sense approach to enhancing animal welfare, product quality and safety, worker safety, and

environmental and economic sustainability. The larger and more intense the facility, the more detailed are the associated GAqPs, as well as the record keeping. If situations change over time, so should the GAqPs. Good aquacultural practices should be adjusted whenever there are intended or unintended changes. Good aquacultural practices and the documentation that accompanies them will enhance buyer confidence and producer accountability.

Συνοπτική Περιγραφή

Οι άξονες της Αειφορικής διαχείρισης Υδατοκαλλιεργειών αφορούν τόσο τις μονάδες καθαυτές, όσο και το ευρύτερο χωροταξικό τους περιβάλλον (όπως της αλυσίδας αξίας της παραγωγής, του τομέα εγκατάστασης, του φυσικού τοπίου, της περιοχής, της περιφέρειας και της χώρας). Οι θεματικές ενότητες επικεντρώνονται στη διοίκηση επιχειρήσεων, στην επιλογή τοποθεσίας, στην αξιολόγηση κινδύνων και στα μέτρα μετριασμού τους, στην κατασκευαστική τους δομή, τη μηχανική τους βάση ή την αποκατάσταση συστημάτων λειτουργίας, στη διαχείριση περιβαλλοντικών επιπτώσεων, στη λειτουργική τους δυναμική, στη βιοασφάλεια και στη διαχείριση της υγείας, στην πρόσβαση προς τις αγορές, στην ασφάλεια τροφίμων, στη διαχείριση της ποιότητας, στην καλή διαβίωση των ιχθύων, στην ασφαλή εργασία του προσωπικού και στις ειδικές επιχειρηματικές δραστηριότητες, συμπεριλαμβανομένων των εντατικών και εκτατικών υδατοκαλλιεργειών, και της υδατοκαλλιέργειας ανοικτής θαλάσσης.

Η αειφόρος ανάπτυξη της υδατοκαλλιέργειας δεν είναι ομοιόμορφη παγκοσμίως και ο τομέας έχει διαφορετικές επιδόσεις σε διαφορετικά περιβάλλοντα, χώρες και περιοχές. Ορισμένες προσπάθειες ανάπτυξης της υδατοκαλλιέργειας απέτυχαν να προωθήσουν την κοινωνικοοικονομική και περιβαλλοντική πρόοδο, ενώ άλλες προσπάθειες έχουν αποδειχθεί επιτυχημένες.

Τα διαχειριζόμενα εκτεταμένα συστήματα ιχθυοκαλλιέργειας και ολοκληρωμένα πολυτροφικά συστήματα υδατοκαλλιέργειας (IMTA), μπορούν ουσιαστικά να γίνουν κάτι πολύ περισσότερο από την ιχθυοκαλλιέργεια. Αυτές οι λειτουργίες ιχθυοπαραγωγής μπορεί διαχειριστούν με τρόπο που να οδηγήσει σε αποκατάσταση των ζημιών που προκλήθηκαν σε υγροτόπους από προηγούμενες χρήσεις γης, ελαχιστοποιώντας το δικό τους οικολογικό αποτύπωμα και συνδυάζοντας τα οικονομικά οφέλη της υδατοκαλλιέργειας στοχεύοντας στη διατήρηση. Ωστόσο, τα οφέλη που παρέχουν στους υγρότοπους οι βιώσιμες πρακτικές σε εκτεταμένα συστήματα υδατοκαλλιέργειας και πολυκαλλιέργειας και ο ρόλος αυτών των δραστηριοτήτων στην αποκατάσταση του οικοσυστήματος, είναι γνωστά μόνο σε τοπική κλίμακα.

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Η παραγωγή θαλασσινών υδατοκαλλιέργειας είναι η ταχύτερα αναπτυσσόμενη παραγωγή τροφίμων παγκοσμίως και πρέπει να αναπτυχθεί ώστε να είναι περιβαλλοντικά περισσότερο βιώσιμη. Αυτό ισχύει επίσης για την Αλβανία, την οποία αφορά η συγκεκριμένη ανάλυση και το παραδοτέο. Υπάρχουν ακόμη αρκετοί τρόποι για τη μείωση των επιπτώσεων των υπαρχόντων ή των νέων συστημάτων υδατοκαλλιέργειας και ανακεφαλαιώνονται παρακάτω βασικές συστάσεις με βάση τα ευρήματα της παρούσας μελέτης, αλλά και τα αποτελέσματα και την ανάλυση από άλλες μελέτες της σχετικής βιβλιογραφίας.

Οι καλές πρακτικές υδατοκαλλιέργειας είναι μια προσέγγιση κοινής λογικής για τη βελτίωση της καλής διαβίωσης των ζώων, της ποιότητας και της ασφάλειας των προϊόντων, της ασφάλειας των εργαζομένων και της περιβαλλοντικής και οικονομικής βιωσιμότητας. Όσο μεγαλύτερες είναι οι εγκαταστάσεις, τόσο πιο λεπτομερείς είναι οι σχετικές καλές πρακτικές, καθώς και η τήρηση αρχείων. Εάν οι καταστάσεις αλλάζουν με την πάροδο του χρόνου, το ίδιο ισχύει και για τις καλές πρακτικές. Οι καλές πρακτικές υδατοκαλλιέργειας πρέπει να προσαρμόζονται όποτε υπάρχουν σκόπιμες ή ακούσιες αλλαγές. Οι καλές πρακτικές υδατοκαλλιέργειας και η τεκμηρίωση που τις συνοδεύει θα ενισχύσουν την εμπιστοσύνη των αγοραστών και την υπευθυνότητα των παραγωγών.

Introduction

Aquatic supply chains, based on e.g. fish, molluscs, crustaceans and algae, provide products aimed for direct or indirect human consumption and other uses. Global demand for these products is increasing, but the fact that wild-capture fisheries—supplying inputs for the food and feed industries—have stagnated (FAO 2016), or even declined (Pauly and Zeller 2016), has raised questions about the environmental consequences of aquatic supply chains (Ziegler et al. 2016). Research applying LCA to seafood products has emerged since the early years of the century and, until today, dozens of case studies of fisheries and aquaculture systems from all around the world have been published. The body of literature in this field has grown to the extent of allowing systematic reviews to be undertaken on specific production sectors, such as for capture fisheries (Vázquez-Rowe et al. 2012; Avadí and Fréon 2013) and aquaculture (Henriksson et al. 2012).

Aquaculture carries the risk of negative impacts on the environment surrounding the farm by emitting pollutants and organic waste derived from feed, both in dissolved (ammonium, urea, etc.) and particulate (uneaten feed and feces), which can change ecosystems and influence biodiversity, as well as due to their use of natural resources from different ecosystems (e.g. fish feed, raw material) (Abdou et al., 2018).

Aquaculture has an important role to play both in terms of quality food supply and the economic development of coastal and inland rural areas. While showing a slight improvement after many years of stagnation, the EU aquaculture sector is still far from reaching its potential. The EU imports two thirds of the seafood it consumes. The gap between EU high fish consumption (23.1 kg per person and per year) and the production of EU capture fisheries has been steadily growing in the last years. Even when fished at Maximum Sustainable Yield (MSY) levels, fisheries alone cannot satisfy the growing demand for seafood. While sustainable aquaculture products would be able to address this gap, also alleviating pressure on wild stocks, aquaculture in the EU represents only around 10% of EU seafood consumption. Ref. Ares (2020)1736411 - 24/03/2020. The sector’s development has been hampered by several types of barriers. Some of these barriers were already identified in the current Strategic Guidelines, such as complex administrative procedures or access to space, where EU

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Member States have made some but not sufficient progress. EU aquaculture also faces new challenges such as the impact of climate change. Finally, promoting sustainable EU aquaculture can play an important role in addressing some of current policy challenges identified in the political priorities of the new Commission, such as decarbonisation, circularity, combating pollution (e.g. algae and molluscs farming can help address nutrient pollution), food security, and the preservation of rural and coastal communities.

Intensive aquaculture facilities, especially fish cages, have negative impacts on fragile habitats and sensitive species. Conversely, extensive fish farming systems and integrated multi-trophic aquaculture systems (IMTA) effectively restore the flow of water into and out of the degraded wetlands, restablishing the transport of nutrients, nutrient cycling, water quality, flood storage, and many other abiotic conditions largely disturbed, and attracting local fauna. Extensive aquaculture models are based on large fish growing ponds connected to each other and with the neighboring rivers by means of irrigation and drainage canals. Typical fishponds are earthen enclosures in which the fish live in a natural-like environment, feeding on the natural food growing in the pond itself from sunlight and nutrients available in the pond water. Fishponds are usually surrounded by reed belts and natural vegetation, thus providing important habitats for flora and fauna, and acting as huge water treatment plants where the excess of nutrients (nitrogen, phosphorus, etc.) and organic matter are removed and naturally transformed into living biomass. With the combination of extensive stabilization ponds, fishponds and macrophyte ponds, the original nutrient removal efficiency of a disturbed wetland can be restored and enhanced. Furthermore, by the integration of valuable fish and plant species, these nutrients can be converted into marketable by-products.

The increased production-inputs suggest a similar range of production-outputs, potentially coupled with environmental impacts, comprising mainly airborne and waterborne emissions from the farms. These emissions may result in local ecosystem imbalances, particularly when carrying capacity is exceeded in the recipient water body. Recently, however, important global scale impacts that may arise during aquaculture production, such as global warming, acidification, ozone layer depletion, have gained popularity in environmental studies.

Undoubtedly, the growing importance of global aquaculture demands for the evaluation and adaptation of quantitative tools for the identification of hot spots for potential technical improvements regarding economic efficiency, environmental and social concerns. Assessing aquaculture environmental impact and examining the array of multi-impact assessment tools already used in case studies will, therefore, highlight the limitations and suggest needs/options for improvement.

Among the multi-impact tools used, Ecological Footprint (EF) and Life Cycle Analysis (LCA) represent methodologically the most advanced tools and are increasingly used in aquaculture studies. Both aim at providing a complete picture of a product’s environmental impacts and attempt to avoid problem shifting.

AQUACULTURE’S KEY CHALLENGES

Before moving to the Guidelines, we must identify the key challenges that an aquaculture farm faces.

Conflicts with other resource users: Aquaculture commonly requires the allocation of public space (land, coastal, marine area, or freshwater) and may cause significant habitat conversion or modification. This can have direct and indirect impacts on all resource users if access rights and equity are not properly accounted for. Included here are conflicts that arise because of inadequate protection of high-value and sensitive ecosystems.

Exceeding waterbody carrying capacity: Many types of aquaculture are dependent on a reliable supply of good-quality water, and aquaculture is rarely the sole user of a water body. Aquaculture is directly impacted by upstream users and directly impacts downstream users through the release of waste products into the surrounding environment. Exceeding the environmental carrying capacity (or assimilative capacity) of a waterbody leads to negative environmental impacts (e.g., eutrophication, hypoxia, benthic impacts, and groundwater abstraction) and loss of ecosystem services.

Disease amplification and transmission: Disease is a major limiting factor in most aquaculture production. It is costly, not only due to reduced growth and increased mortality in stocks — and the associated additional resource use — but also due to the costs associated with treatment, control, and management. Certain pathogens, such as those listed by the World Organisation for Animal Health (OIE) can also have implications on trade, reducing the ability to export animals and in some cases commodities to other areas or countries free of those pathogens. Pathogens associated with aquaculture may also pose a risk to wild aquatic animal stocks, which can be detrimental to both the environment and the industry's reputation.

1. Guidelines

1.1. The ecosystem approach to aquaculture

The ecosystem approach to aquaculture (EAA) was established by FAO in 2008 and further detailed in 2010. It is generally considered the most appropriate framework for integrated management of aquaculture and is defined as a "strategy for the integration of the activity within the wider ecosystem, such that it promotes sustainable development, equity, and resilience of interlinked social-ecological systems." The EAA was developed on three principles, which are that aquaculture must:

- Be in harmony with its environment
- Be beneficial for the local people involved
- Recognize and facilitate the co-use of different activities.

Aquaculture concerns include:

Spatial Planning and Zoning: the process through which public and private sectors aim to influence the spatial distribution of people and activities at differing geographic scales. There are numerous users of the marine environment (e.g., aquaculture, tourism, fisheries, marine transport), and many of these users differ dramatically in terms of their objectives, goals, and resource needs, often putting them in direct conflict with each other. To date, most development has been done on an ad hoc basis, with little consideration of interactions and long-term sustainability. Many examples demonstrate that inadequate planning can lead to adverse environmental impacts, lack of economic feasibility, and/or social conflict. Marine spatial planning is a systematic process through which the public and private sectors work together to influence the spatial distribution of people and activities at differing geographic scales. This process is a fundamental component of ensuring successful and sustainable aquaculture development, and has been shown to minimize conflicts between competing users and maximize overall value of the marine environment

Waterbody Carrying Capacity Limits: determining the level of resource use, by all resource users, that can be sustained over the long term without harming ecosystems or provision of ecosystem services.

Aquaculture Management Areas: waterbodies, or parts thereof, where certain management practices are coordinated across all aquaculture operators in the area, to minimize cumulative impacts and risks.

1.2. Main objective of the Guidelines

Main objective of the Guidelines on Aquaculture is the promotion of a sustainable aquaculture that creates growth and jobs and contributes to food security and supplies. According to this regulation, the Guidelines should further aim at a) improving the competitiveness of the aquaculture industry and supporting its development and innovation; b) reducing the administrative burden and making the implementation of law more efficient and responsive to the needs of stakeholders; c) encouraging economic activity; d) diversification and improvement of the quality of life in coastal and inland areas; e) Integrating aquaculture activities into maritime, coastal and inland spatial planning. The Guidelines on Aquaculture ensure that these objectives are pursued, by providing updated strategic guidance. Furthermore, they also contribute to achieving the objectives such as the Farm to Fork Strategy and the Green Deal, in particular in terms of social and environmental sustainability and climate change adaptation and mitigation efforts.

Despite its successful growth and potential, aquaculture is not consequence- or impact-free. With the rapid expansion of aquaculture in the past three decades — often in under-managed or underregulated environments — the industry has experienced boom and bust cycles and acquired a negative reputation for its associated environmental impacts, particularly in Western markets. The direct environmental impacts of aquaculture are well-documented and include habitat loss in critical ecosystems (e.g., mangroves and wetlands), nutrient loading that contributes to poor water quality, the introduction of invasive species, and

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the spread of disease. These impacts can have severe ramifications but can often be addressed by proper and effective management of the aquaculture industry. Typically, aquaculture has been developed in an ad-hoc manner, and management has largely focused on siting, licensing, and monitoring performance and impact at the farm level. This perspective fails to acknowledge that aquaculture industries are dependent on common pool resources (namely water and space) and are tightly coupled to the ecosystems in which they operate. Not only are individual farms interacting and competing with one another for shared resources, but the aquaculture industry is also interacting and competing with other users of those shared resources. As such, siting and managing aquaculture at the farm level has not been sufficient to mitigate the cumulative negative environmental impacts of all resource users, often proving detrimental to aquaculture industries by creating user conflicts, failing to protect aquaculture from the impacts of other industries, and detracting from the benefits of aquaculture.

Contribution of different system components: Large environmental impacts may stem from specific stages or components within the life cycle of the aquaculture systems (like feed production, energy supply or fish production) and thus constitute environmental hotspots of the systems.

Seafood farming stage: The production stage is a key driver of aquatic eutrophication impacts due to nitrogen and phosphorus emissions from uneaten feed and fish faeces. This impact category has been identified as one of the most important when studying aquaculture production. The production stage is also identified as the main source of water dependence. This impact category, specific to aquaculture production, refers to the water input relative to the fish production in mass of biota (Aubin et al. 2009). By better combining water management and nutrient input systems, an improved aquaculture production could thus be possible.

Feed production and influence of FCR: Feed production is found to be a key driver of cumulative energy demand (58% of the studies), net primary production use (86% of the studies), acidification (63% of the studies) and climate change (56% of the studies). The FCR is believed to be the main cause of these results. Indeed, 56% of the studies have explicitly stated that FCR has a main influence on the environmental impacts. The FCR reflects the quantity of aquafeed needed per animal weight gain during production

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and is specific to a farming site. It is influenced by multiple factors, like the feed composition, the technology used, the fish species and the mortality at the site. All these factors offer possibilities for improvements that should be considered to overall decrease the FCR. Specific improvements related to decreasing impacts of feed production are further discussed in Section ‘Improving feed production’.

Energy supply systems: The choice of energy supply is important for the environmental performance of aquaculture systems. Over a third of the studies concluded that the energy context, including the geographical situation (determining the composition of the electricity grid mixes), had an influence on the environmental impacts. It is worth highlighting that this conclusion has not only been drawn about farms using recirculating aquaculture systems, but also when considering flow-through floating tanks, traditional and cascade flow through systems, offshore aquaculture systems or shellfish production farms. Indeed, the different electricity production means present considerably different environmental impacts because the different energy sources and technologies have distinct emissions and resource uses. For example, fossil-fuel-based electricity production (such as coal or natural gas power plants) has much higher climate change impacts than electricity mixes based on hydropower, solar power or wind power, whereas the opposite tends to be observed for metal depletion.

1.3. Guidelines towards sustainable aquaculture

1) Assessing aquaculture environmental impact

Examining the array of multi-impact assessment tools already used in case studies highlights the limitations and suggest needs/options for improvement. The most widely-used impact assessment methods cover climate change arising from greenhouse gas emissions, acidification from acid gas emissions, eutrophication as a result of nitrifying emissions (such as nitrate, ammoniacal nitrogen and phosphates), the release of ozonedepleting substances, and abiotic and biotic resource depletion (Pelletier et al., 2007). These multi-impact categories encompass global impacts departing from the traditional single impact assessment tools.

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There are several methodologies, techniques and tools available for use in environmental assessments of products or systems. Traditional environmental evaluation methods generally focused on a single environmental problem such as nutrient discharge or energy use. In the last two decades, however, increasing effort is underway in developing multi-impact methods, assessing several environmental issues.

Among the multi-impact tools used, Ecological Footprint (EF) and Life Cycle Analysis (LCA) represent methodologically the most advanced tools and are increasingly used in aquaculture studies. Both aim at providing a complete picture of a product's environmental impacts and attempt to avoid problem shifting. Problem shifting involves a shift in production in order to reduce identified environmental impacts by shifting their form or location of release. For example, by taking a holistic multi-impact approach these tools consider all emission forms globally, hence avoid geographic problem shifting. Analysing several potential impacts such as energy expenditure and emissions, impact-specific problem shifting is avoided. Suitable zones should have abundant water resources and adequate water quality for target species. In addition, planners should consider how aquaculture's impact on the water column, benthic environment, and surrounding sensitive ecological areas and populations might impact other users (e.g., wild-caught fisheries, tourism) when selecting areas.

2) Assessing Economic efficiency

Declines in available fishing grounds, navigational disturbances, variation in landings, and competition with fish farmers for catches have all been observed following the introduction of aquaculture to an area. Small-scale fisheries are often limited to nearshore coastal areas due to vessel size and power constraints. Spatial conflicts between these fisheries and aquaculture are likely to increase in the future as nearshore and coastal space becomes increasingly scarce. Conversion to coastal shrimp and fish ponds can also privatize public lands that were formerly accessible to small-scale fishers and intertidal gleaners. Products from wild fisheries and aquaculture compete in the market, affecting the prices that fishers and farmers receive, as well as the demand for seafood products. The result is a higher, more resilient global seafood supply with lower prices and reduced price volatility. However, at the fishery level, the effects of market competition depend on numerous factors, including the species and technologies involved, the degree of substitutability between products, the fishery management in place, and the presence of other interactions (spatial, ecological) outside of the market.

3) Assessing Social concerns

Aquaculture is ideally placed in areas with few existing users (e.g., shipping, tourism, wild-caught fisheries) to minimize potential user conflicts, and areas with access to production infrastructure (e.g., roads, energy) and markets for both inputs and outputs. Social risks are challenges by stakeholders to companies' business practices due to real or perceived business impacts on a broad range of issues related to human welfare – for example, working conditions, environmental quality, health or economic opportunity. The consequences may include brand and reputation damage, heightened regulatory pressure, legal action, consumer boycotts and operational stoppages – jeopardizing short- and long-term shareholder value. This definition of social risk can be suitably adapted for aquaculture at the sector, industry, company, farmer group or individual farm level. The definition provides a departure to the concept of origin of risk. To bring social risk analysis to a degree of simplification and system, one should start by defining aquaculture's spheres of social responsibility; identifying the stakeholders to which it has to be responsible and drawing from codes of conduct, codes of practices, ecolabeling and certification schemes, labor standards, food safety standards and environmental standards a list of hazards that could turn into social risks.

Another point of difference between social and other risks is that social risks are strategic risks. For strategic risks, in contrast to traditional compliance or hazard risks, risk and opportunity are two sides of the same coin. This makes it necessary and desirable to adopt an integrated approach to strategic risk management. A strategic risk that is anticipated early and mitigated well can be converted into a new market, a competitive advantage, a stock of goodwill or a strategic relationship. An aquaculture risk data bank could be created in which all possible hazards and risks are classified as to their nature, causes, consequences, impacts, severity of impacts, likelihood of occurrence and other characterizations.

It is common to read headlines that decry aquaculture's detrimental effects on the environment and yet difficult to find news stories about its importance as a provider of livelihoods worldwide. Aquaculture notably affects people and societies far beyond obvious contributions to food security or any positive or negative environmental impacts. Globally, 18.7 million people currently work as fish farmers and, as with fisheries, this figure increases by three- to fourfold if secondary and postharvest employment is included (FAO 2016). The income earned by each of these employed individuals supports up to four dependents (Smith et al. 2010). Increased training of women and greater participation in the workforce have followed. Employment figures mirror trends of increasing production data over the past years as well. Fish farmers now represent one third of all employees involved in fish production. In 2000, 12.6 million fish farmers composed just one quarter of that global total. Macroeconomic benefits derived from export earnings are also self-evident (Smith et al. 2010), but these impressive numbers do not tell the whole story.

Even when aquaculture activities do not return the same economic benefit per unit effort as fishing, aquaculture job demands differ fundamentally from fishing and seasonal (self-)employment, thereby creating distinct advantages (Irz et al. 2007). Aquaculture jobs offer a certainty of location, which allows fish farmers to make choices about family position and housing that improve household stability. This brings many advantages over fishing in terms of access to education, health provision, and appropriate housing. Furthermore, regularity of working hours allows individuals to incorporate further education and other beneficial planned activities into their daily lives. While fisheries may offer higher returns at times of plenty, aquaculture returns are generally more predictable in both time and value. With this advantage, individual farmers are able to make informed financial planning decisions and investments.

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2. Evaluating the environmental footprint of aquaculture farming systems

The rapid expansion of the aquaculture sector has been associated with many sustainability concerns, such as emissions leading to climate change, eutrophication, toxic and ecotoxic impacts, use of antibiotics, use of land and water needed for feed production, loss of biodiversity, introduction of non-indigenous species, spread/amplification of parasites and disease, genetic pollution, dependence on capture fisheries, and socio-economic concerns

There are several methodologies, techniques and tools available for use in environmental assessments of products or systems. Traditional environmental evaluation methods generally focused on a single environmental problem such as nutrient discharge or energy use. In the last two decades, however, increasing effort is underway in developing multi-impact methods, assessing several environmental issues. The major environmental assessment tools in use in aquaculture are introduced in this section. Examples of environmental impact assessment tools include: Environmental Impact Assessment (EIA), Risk Assessment (RA), Technological Assessment (TA), Environmental Management Systems (EMS), Environmental Auditing (EA), Ecological Footprint (EF), and Life Cycle Assessment (LCA).

Among the multi-impact evaluation methods used in aquaculture EF and LCA present the most advanced methodological framework. These evaluating methods show a complete picture of a product’s environmental impacts that avoids problem shifting. Problem shifting involves the shift in production modes, such that, identified environmental impacts are reduced by shifting their form or location of release. By taking a holistic approach, multi-impact methods avoid problem shifting through consideration of all emission forms globally. The implementation of these methods in aquaculture as a tool for environmental analysis is a recent practice, usually taking the model of agricultural production systems.

Aquaculture LCAs often require large system boundaries, including fisheries, agriculture, and livestock production systems from around the globe. The reviewed studies offered limited coverage of production in

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developing countries, low-intensity farming practices, and non-finfish species, although most farmed aquatic products originate from a wide range of farming practices in Asia. Apart from different choices of functional unit, system boundaries and impact assessment methods, the studies also differed in their choice of allocation factors and data sourcing. Interpretation of results also differed amongst the studies, and a number of methodological choices were identified influencing the outcomes

According to ISO 14000 series, the technical framework for LCA methodology (Fig. 1) as it is defined in ISO 14040 consists of four phases:

- goal and scope definition;
- (2) inventory analysis;
- (3) impact assessment; and
- (4) interpretation

Firstly, defining the goal and scope involves defining purpose, audiences and system boundaries. Secondly, the life cycle inventory involved collecting data for each unit process regarding all relevant inputs and outputs of energy and mass flow, as well as data on emissions to air, water and soil. Thirdly, the life cycle impact assessment phase evaluates potential environmental impacts and estimates the resources used in the modeled system. This phase consists of three mandatory elements: selection of impact categories, assignment of life cycle inventory results (classifications) and modeling category indicatory (characterization) classification of the life cycle inventory results involves assigning the emissions, wastes and resources used to the impact categories chosen. The converted life cycle inventory results are aggregated into an indicator result, which is the final result of the mandatory part of a life cycle impact assessment. Finally, the last stage of LCA is the interpretation. This stage identifies significant issues, evaluates findings to reach conclusions and formulate recommendations. The final report is the last element to complete the phases of LCA (Fig. 1).

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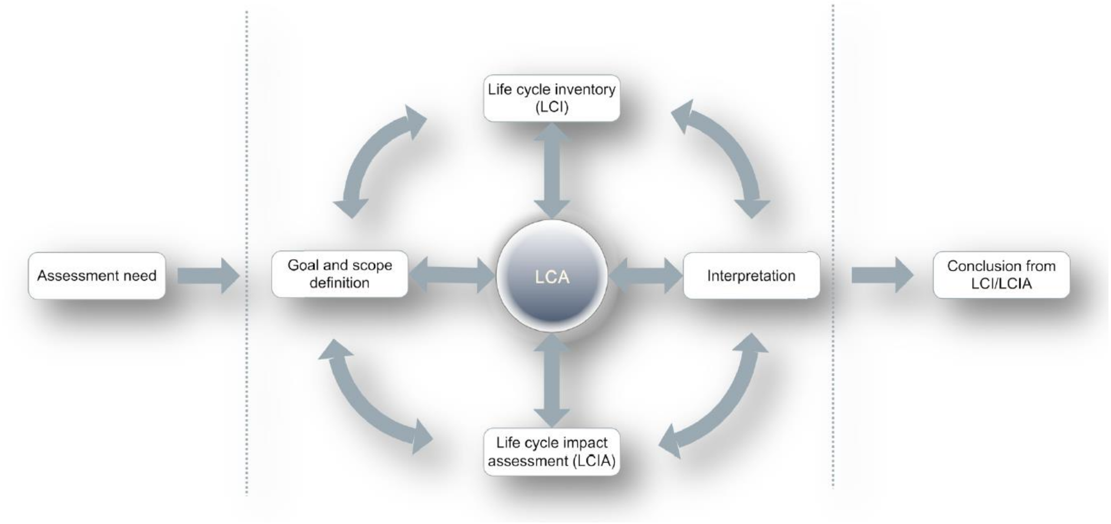

Fig. 1. Life cycle assessment (LCA) framework following ISO 14040 and 14044 standards.

Often, aquaculture systems reveal complex process linkages involving multiple variables that are mostly not parameterized. The diverse and multidisciplinary nature of the environmental aspects and highly variable production processes involved in aquaculture as well as their interlinkages (Fig. 2) impede the development of quantification tools in evaluating the complex interactions. High input of nutrients and organic material from artificial feeding results in nutrient loaded effluents leading to a substantial increase in primary production, subsequent decomposition and biochemical oxygen demand (BOD), limiting the carrying capacity of the recipient aquatic system, although this is highly dependent on the receiving ecosystem. Furthermore, the amount of nutrients and organic load from aquaculture effluents largely depend on the quantity of feed used and utilized by the target organism.

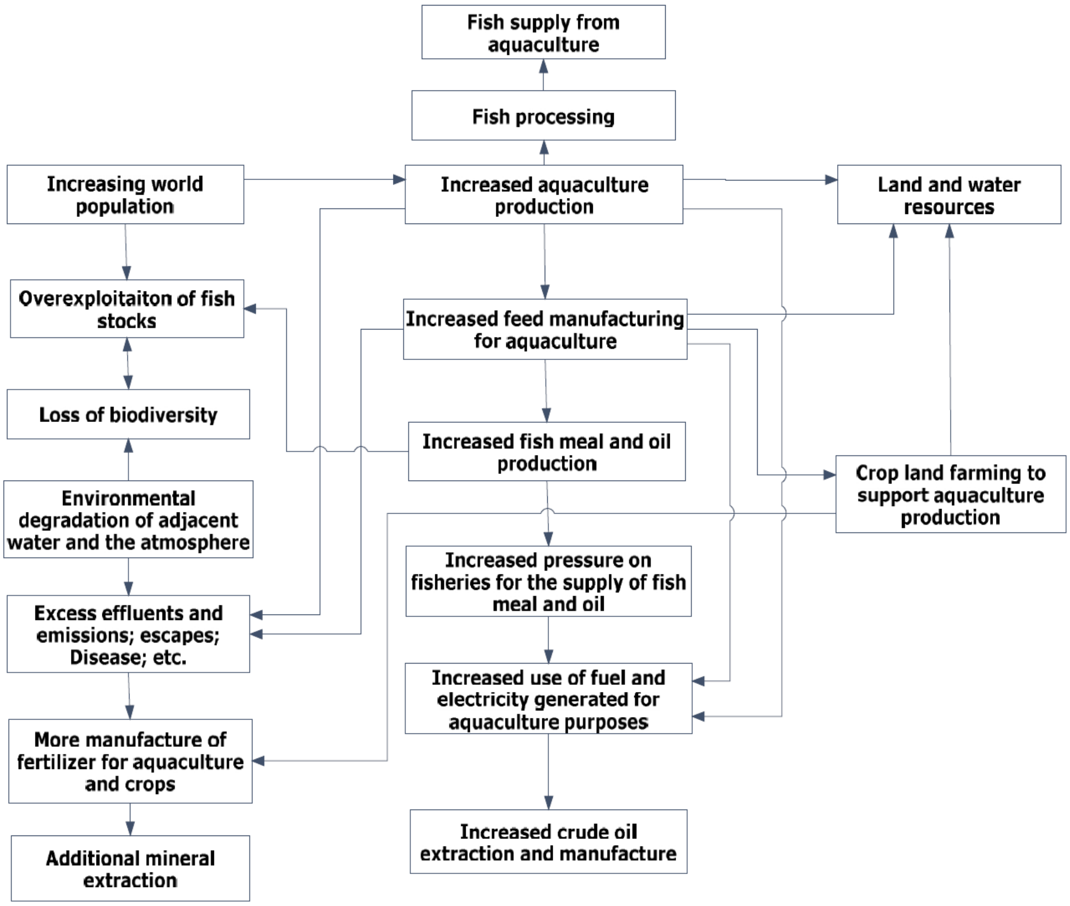

Fig. 2. Major environmental interactions supporting increased aquaculture production.

In ISO 14040 (2006) LCA is defined as the "compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle". Thus, LCA is an assessment tool of the resources used and the environmental impacts throughout a product’s life cycle, i.e., from raw material acquisition, via production and use phases, to waste management. The methodological development in LCA has been strong, and LCA is broadly applied in practice. An LCA tool can assist in:

- Product improvement, by identifying opportunities to improve the environmental performance of products at various points in their life cycle,
- Strategy and policy development, by informing decision-makers in industry, government or non-government organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign),

- Product comparison, with the selection of relevant indicators of environmental performance, including measurement techniques, and
- Product design and development / marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).

According to ISO 14040 (2006), LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA to assess such impacts. LCA is an approach which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the LCI and consequently the LCIA profile are related to the functional unit. LCA is an iterative technique. The individual phases of an LCA use the results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results. Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCAs, in order to ensure a proper interpretation of the results. LCA considers all attributes or aspects of natural environment, human health and resources. By considering all attributes and aspects within one study, potential trade-offs can be identified and assessed.

Goal and scope definition: 1st phase

The goal and scope definition is the phase in which the initial choices which determine the working plan of the entire LCA are made. The goal is formulated in terms of the exact question, target audience and intended application. The scope of the study is defined in terms of temporal, geographical and technological coverage, and the level of sophistication of the study in relation to its goal. Finally, the product (or products), that is the object of the analysis, is described in terms of function, functional unit and reference flows.

In order to define the goal of an LCA, the following items shall be unambiguously stated (ISO 14044:2006):

- the intended application
- the reasons for carrying out the study

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- the intended audience, i.e. to whom the results of the study are intended to be communicated
- whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

Additionally, the scope of an LCA is defined when the most of the following items are clearly described:

- the product system[1] to be studied
- the functions of the product system or, in the case of comparative studies, the systems
- the functional unit
- the system boundary
- allocation procedures, if they are necessary
- LCIA methodology and types of impacts
- interpretation to be used
- data requirements
- assumptions
- value choices and optional elements
- limitations
- data quality requirements
- type of critical review, if any
- type and format of the report required for the study.

The goal and scope definition of an LCA provides a description of the product system in terms of the system boundaries and a functional unit. All the previously referred items should be considered in this phase, but the determination of the functional unit and the system boundary are of great importance. The scope of an LCA shall clearly specify the functions (performance characteristics) of the system being studied. One of the primary purposes of a functional unit is to provide a reference to which the input and output data are normalized (in a mathematical sense). Therefore the functional unit shall be clearly defined and measurable (ISO 14044:2006). The functional unit is the important basis that enables alternative goods, or services, to be compared and analysed. Comparisons between systems shall be made on the basis of the same function(s),

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[1] Product system: The total system of unit processes involved in the life cycle of a product, where unit process is the smallest element considered in the life cycle inventory analysis for which input and output data are quantified (ISO 14010:2006)

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quantified by the same functional unit(s) in the form of their reference flows. The functional unit is not usually just a quantity of material; it can be the service that the product provides. For example, alternative types of packaging may be compared on the basis of 1 m^3 of packed and delivered product. The amount of packaging material required, termed the reference flow, can vary depending on the packaging option selected (paper, plastic, metal, composite, etc.).

The system boundary, as the second important step, determines which unit processes shall be included within the LCA. The selection of the system boundary shall be consistent with the goal of the study. Decisions shall also be made regarding which inputs and outputs shall be included and the level of detail of the LCA shall be clearly stated. It is helpful to describe the system using a process flow diagram showing the unit processes and their inter-relationships; where the unit process begins, in terms of the receipt of raw materials or intermediate products; the nature of the transformations and operations that occur as part of the unit process; where the unit process ends, in terms of the destination of the intermediate or final products (ISO, 14044:2006). The results from goal and scope definition form the input for the next phase of the LCA, the Inventory Analysis.

The choices and assumptions made during system modelling especially with respect to the system boundaries and what processes to include within these boundaries, are often decisive for the result of an LCA study. An understanding of the importance of system modelling in LCA has been growing ever since “goal and scope definition” was identified as a separate phase. Two very distinct categories of LCA goals exist:

- to describe a product system and its environmental exchanges or
- to describe how the environmental exchanges of the system can be expected to change as a result of actions taken in the system.

In recent years, the most used distinction between types of LCA has been “*attributional and consequential LCA*”. Attributional LCA is defined by its focus on describing the environmentally relevant physical flows to and from a life cycle and its subsystems. Consequential LCA is defined by its aim to describe how environmentally relevant flows will change in response to possible decisions. The distinction between attributional and consequential

LCA has important consequences for the way the product system should be modelled.

Inventory analysis: 2nd phase

LCI, according to ISO, is a phase of LCA involving the compilation and quantification of inputs and outputs of a product throughout its life cycle (ISO, 14044:2006). An LCI can be best described as a model of one or more product systems. Each product system fulfils a function that is quantified in functional units. The aim of the LCI is to calculate the quantities of different resources required and emissions and waste generated per functional unit. To make an inventory analysis means to construct a flow model of product system. The model of the product system is composed of unit processes, which each represent one or several activities, such as production processes, transport, or retail. For each unit process, data are recorded on the inputs of natural resources, the emissions, waste flows, and other environmental exchanges. All unit processes are linked through intermediate product flows. For product comparisons, the functional unit is translated to reference flows. The model of the product system is an incomplete mass and energy balance over the system, where only the environmentally relevant flows are considered. Environmentally indifferent flows such as diffuse heat and emissions of water vapour as a combustion product are not modelled. LCA models are usually static and linear, meaning that time is not a variable and all relationships are simplified to linear ones. Usually the model is presented as a flow chart (Fig. 3).

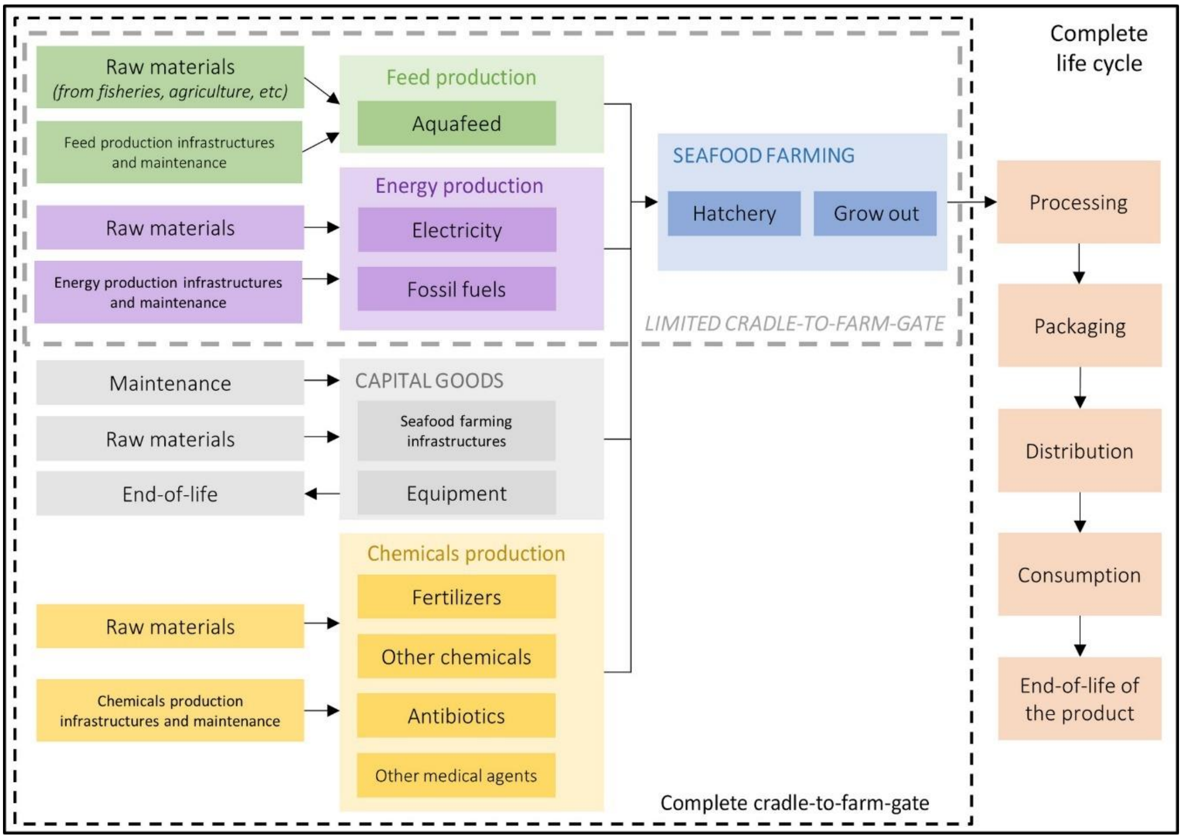

Fig. 3: A flow chart at the inventory phase of the LCA

The process of conducting an inventory analysis is iterative. As data are collected and more is learned about the system, new data requirements or limitations may be identified that require a change in the data collection procedures so that the goals of the study will still be met. Sometimes, issues may be identified that require revisions to the goal or scope of the study (ISO 1440:2006).

System boundaries and Allocation

There are three major types of system boundaries in the LCI:

- between the technical system and the environment,
- between significant and insignificant processes, and
- between the technological system under study and other technological systems.

Sometimes time and geographical limits are mentioned as system boundaries. However, these can be seen as special cases of boundaries towards the environment or towards other technological systems, as referred below.

In relation to the system boundary between the technical system and the environment, it can be noted that an LCA should cover the entire life cycle, although, e.g., cradle-to-gate studies can be called partial LCAs. Thus, the inputs should ideally be traced back to raw materials as found in nature. For example, crude oil can be an input to the life cycle, but not diesel oil since the latter is not found in nature but produced within the technical system. In parallel, the outputs should ideally be emissions to nature (Finnveden, et al., 2009). Inputs to the system that have been drawn from the environment without previous human transformation and outputs released to the environment without subsequent human transformations are both called “elementary flows” in the ISO standard (ISO, 14040:2006).

In many cases, the system boundary between the technical system and the environment is obvious. However, when the life cycle includes forestry, agriculture (Audsley et al., 1994; Guinee et al., 2002), emissions to external wastewater systems, and landfills, the system boundary needs to be explicitly defined. At landfills, the system boundary towards the environment can have a time dimension (Finnveden, et al., 2009).

The system boundary between significant and insignificant processes is difficult since it is generally not known in advance what data are insignificant. A general approach can be to include easily accessible data, check the importance of the data, and refine if necessary. The development of better databases and the use of input–output analysis increase the possibilities of separating significant from insignificant processes (Finnveden, et al., 2009).

An LCA is often restricted to a product that is produced and/or used in a specific geographical area during a specific time period. It can also be limited to a specific production technology or to a level of technology (e.g., best available technology). The system boundary towards other technological systems also has to be defined, for example, when the LCA includes the so-called multi-functional processes. These occur when a process is shared between several product systems, and it is not clear to which product the environmental impacts should be allocated (Finnveden, et al., 2009). Allocation is one of the most discussed methodological issues

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in LCA (Weidema, 2003; Lundie et al., 2007). There are two principally different ways of handling multifunctional processes. One is to allocate (partition) the environmental impacts between the products. The other principle to approach the allocation problem is to avoid it by dividing the processes into sub-processes or expanding the system boundaries and include affected parts of other life cycles in the technological system under study (Baumann and Tillman 2004). ISO 14044 (2006) gives some guidance on how to handle allocation problems. It states that whenever possible, subdivision or system expansion should be used to avoid allocation problems. If that is not possible, an allocation reflecting the physical (or chemical or biological) causations should be used if possible, and finally, if that is not feasible, allocation based on other measures, such as economic value (Guinee et al., 2004), mass, or energy, may be used.

Development of databases

An LCI requires a lot of data. Setting up inventory data can be one of the most labour- and time-intensive stages of an LCA. This is often challenging due to the lack of appropriate data for the product system under study (e.g., for chemicals production). In order to facilitate the LCI and avoid duplication in data compilation, many databases have therefore been developed in the last decades. These include public national or regional databases, industry databases, and consultants' databases that are often offered in combination with LCA software tools (Finnveden, et al., 2009).

National or regional databases, which evolved from publicly funded projects, provide inventory data on a variety of products and basic services that are needed in every LCA, such as raw materials, electricity generation, transport processes, and waste services as well as sometimes complex products. Among them are the Swedish SPINE@CPM database (CPM, 2007), the German PROBAS database (UBA, 2007), the Japanese JEMAI database (JEMAI, 2007; Narita et al., 2004), the US NREL database (NREL, 2004), the Australian LCI database (RMIT, 2007), the Swiss ecoinvent database (Ecoinvent, 2007), and the European Reference Life Cycle Database (ELCD) (European Commission, 2007a). Further databases are currently under development all over the world, for example, in Brazil, Canada, China, Germany, Malaysia, Thailand, and other countries.

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Complementary to public LCA/LCI databases, and often a major source of their data, numerous international business associations have created their own inventory datasets as a proactive effort to support the demand for first-hand industry data. Among others, life cycle inventories are available from the aluminium (EAA, 2007), copper (Deutsches Kupferinstitut, 1995), iron and steel (IISI, 2007), plastics (APME, 2007), and paper and board (FEFCO, 2006) industries, covering a wide range of economic activities from extraction of, for example, metal resources to the manufacturing of combinations of materials such as metals alloys and corrugated board.

Some databases, such as the ecoinvent and the US NREL databases, provide also data modules used to build inventories on a disaggregated unit-process level (e.g., for a chemical processing facility with multiple products such as a refinery). This means that the inputs and outputs are recorded per production step, in addition to aggregated data sets (e.g., cradle-to-gate). In contrast, many other databases, such as most of the databases provided by industry associations, supply inventory data as already-aggregated results (such as cradle-to-gate sub-systems), which specify the elementary flows (resource expenditures, emissions, and wastes) aggregated for all processes involved, for example, per mass unit of product manufactured (Finnveden, et al., 2009).

Both aggregated and unit-process data sets are useful for modelling processes in LCA. Aggregated data are often used as background data for modelling the production of, e.g., aluminium, steel, electricity, etc., where the exact source of the material or energy is not available, except possibly the region or market. This is particularly the case for globally traded products. Unit process data, in contrast to average data, often refer to specific technologies. This provides the possibility for tailored inventories, choosing the technologies that are investigated, and allowing the study to focus on. This is particularly useful when a specific chain of processes is being considered and for foreground data where there is a good knowledge of what technologies are used. Furthermore, unit process data allow reviewing the underlying details of the process data and methodological choices, make changes in an inventory such as for the energy mix used, and sometimes even to choose another allocation principle (Finnveden, et al., 2009).

The majority of database systems are based on average data representing average production and supply conditions for goods and services, and thus employs the attributional modelling approach. Quality and consistency are key issues related to inventory data (Finnveden, et al., 2009).

Impact assessment: 3rd phase

The impact assessment phase of an LCA aims at evaluating the significance of potential environmental impacts using the LCI results. In general, this process involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts. The selection of impact categories, category indicators and characterization models shall be both justified and consistent with the goal and scope of the LCA. Impact category is a class representing an environmental issue of concern to which LCI analysis results may be assigned, while impact category indicator is the quantifiable representation of the impact category (Fig. 2-9) (ISO 14040:2006). Characterization models reflect the environmental mechanism by describing the relationship between the LCI results, category indicators and, in some cases, category endpoint(s). The characterization model is used to derive the characterization factors. The environmental mechanism is the total of environmental processes related to the characterization of the impacts (ISO 14044:2006). The category indicator can be chosen anywhere along the environmental mechanism between the LCI results and the category endpoint(s). The Figure 4 illustrates the concept of category indicators based on an environmental mechanism. The impact category "acidification" is used in as an example. Every impact category has its own environmental mechanism.

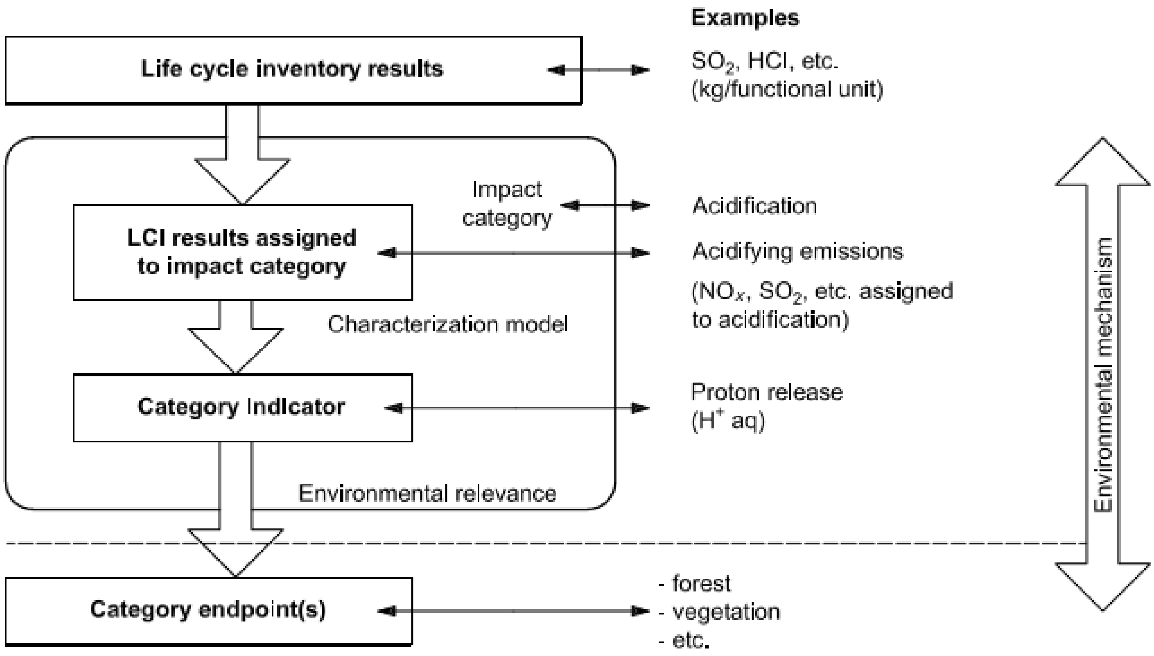


Fig. 4. Concept of category indicators (ISO 14044:2006)

The LCIA addresses only the environmental issues, the level of detail, the choice of impacts evaluated and the methodologies that are specified in the goal and scope. LCIA consists of both mandatory and optional elements, as illustrated in Figure 2-10 (ISO 14044:2006).

Mandatory elements:

- Selection of the impact categories of interest, the indicators for each **impact category** and, the underlying models (a procedure also considered in the initial goal and scope phase of an LCA).
- Assignment of the inventory data to the chosen impact categories (**classification**).
- Calculation of impact category indicators using characterisation factors (**characterisation**).

Optional elements:

- Calculation of category indicator results relative to reference values(s) (**normalisation**).
- Grouping and/or weighting the results (**weighting** not being allowed when following ISO 14044 in comparative assertions disclosed to the public).

- Data quality analysis (mandatory in comparative assertions disclosed to the public, according to ISO 14044, but receiving little attention in current practice).

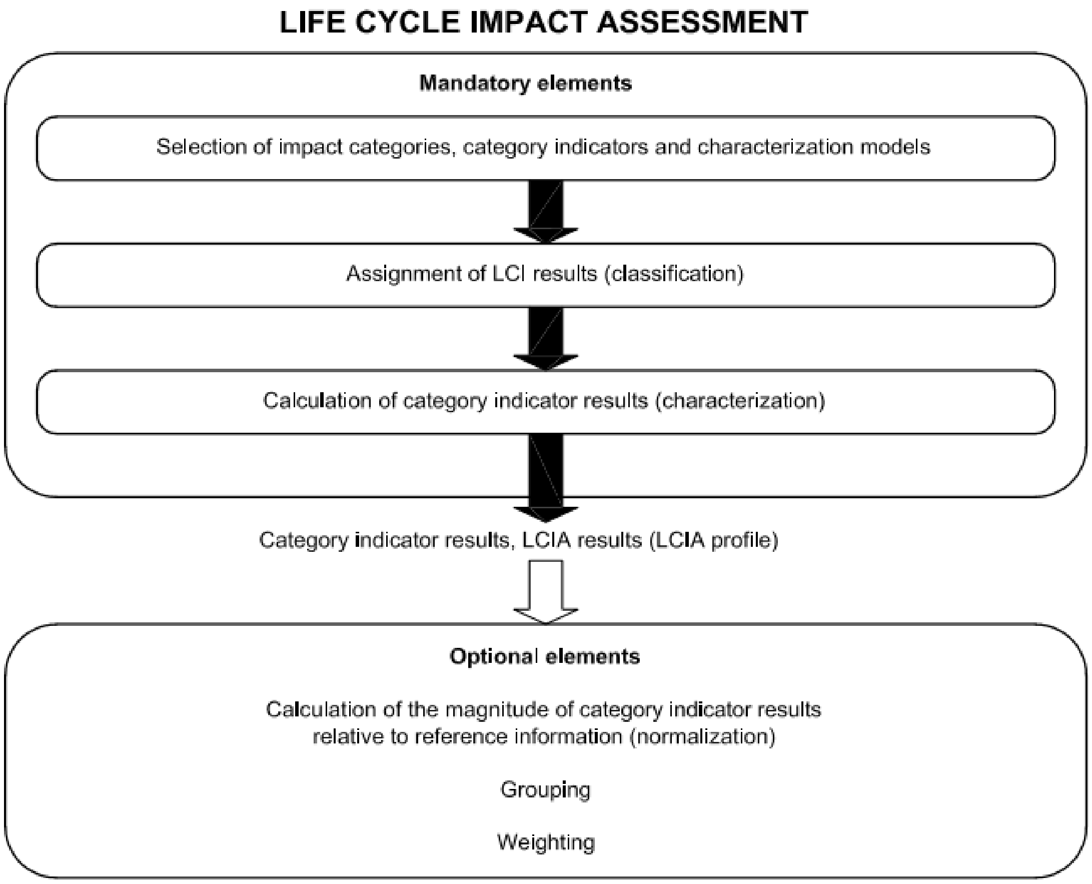


Fig. 5. Elements of LCIA (ISO14040:2006)

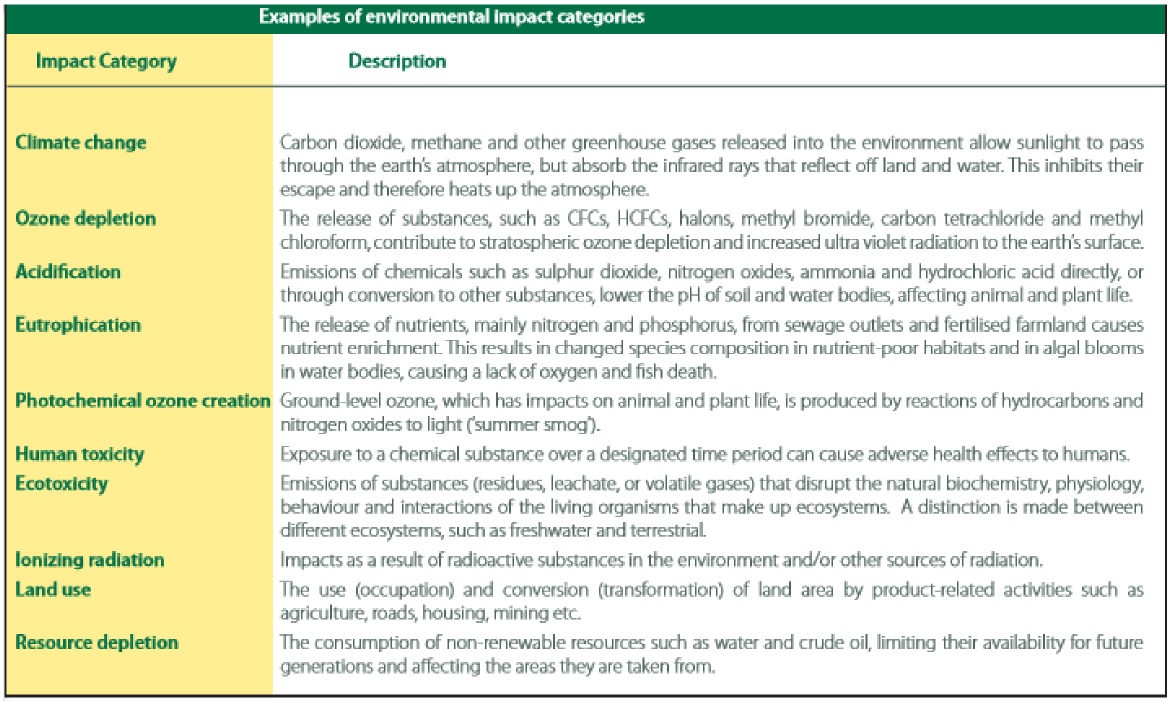
The LCIA phase also provides information for the life cycle interpretation phase and furthermore it reviews if the objectives of the goal and scope phase have been met, or if cannot be achieved. Issues such as choice, modelling and evaluation of impact categories can introduce subjectivity into the LCIA phase. Therefore, transparency is critical to the impact assessment to ensure that assumptions are clearly described and reported (ISO 14040:2006).

Impact categories and AoPs

According to ISO 14044, there are three broad groups of impact categories that should be taken into account when defining the scope of an LCA study.

Impact categories include climate change, stratospheric ozone depletion, eutrophication, acidification, resource depletion, etc., as Figure 6 shows. The three broad groups are commonly referred to as AoPs –Areas of Protection (Udo de Haes et al., 1999). The suggested AoPs are:

- human health
- natural environment
- natural resources



Examples of environmental impact categories

Impact Category	Description
Climate change	Carbon dioxide, methane and other greenhouse gases released into the environment allow sunlight to pass through the earth's atmosphere, but absorb the infrared rays that reflect off land and water. This inhibits their escape and therefore heats up the atmosphere.
Ozone depletion	The release of substances, such as CFCs, HCFCs, halons, methyl bromide, carbon tetrachloride and methyl chloroform, contribute to stratospheric ozone depletion and increased ultra violet radiation to the earth's surface.
Acidification	Emissions of chemicals such as sulphur dioxide, nitrogen oxides, ammonia and hydrochloric acid directly, or through conversion to other substances, lower the pH of soil and water bodies, affecting animal and plant life.
Eutrophication	The release of nutrients, mainly nitrogen and phosphorus, from sewage outlets and fertilised farmland causes nutrient enrichment. This results in changed species composition in nutrient-poor habitats and in algal blooms in water bodies, causing a lack of oxygen and fish death.
Photochemical ozone creation	Ground-level ozone, which has impacts on animal and plant life, is produced by reactions of hydrocarbons and nitrogen oxides to light ('summer smog').
Human toxicity	Exposure to a chemical substance over a designated time period can cause adverse health effects to humans.
Ecotoxicity	Emissions of substances (residues, leachate, or volatile gases) that disrupt the natural biochemistry, physiology, behaviour and interactions of the living organisms that make up ecosystems. A distinction is made between different ecosystems, such as freshwater and terrestrial.
Ionizing radiation	Impacts as a result of radioactive substances in the environment and/or other sources of radiation.
Land use	The use (occupation) and conversion (transformation) of land area by product-related activities such as agriculture, roads, housing, mining etc.
Resource depletion	The consumption of non-renewable resources such as water and crude oil, limiting their availability for future generations and affecting the areas they are taken from.

Fig. 6. Environmental impact categories (EU, 2010)

When defining the impact categories, an indicator must be chosen somewhere in the environmental mechanism. Often indicators are chosen at an intermediate level somewhere along that mechanism, at midpoint level; sometimes they are chosen at endpoint level, as shown in Fig. 7.

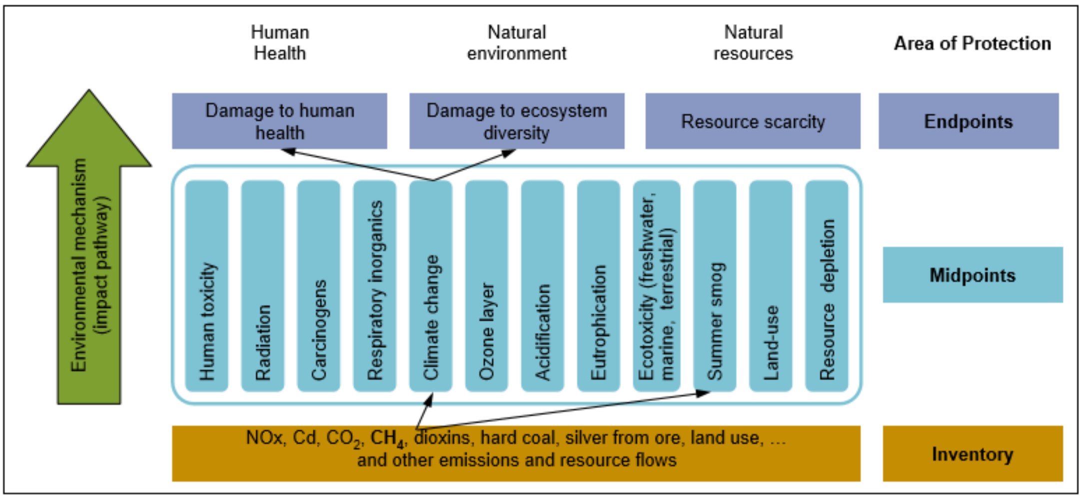


Figure 7. Life cycle impact assessment. Schematic steps from inventory to category endpoints. Note that normalisation and weighting are not shown and can start from either midpoints or endpoints (ILCD, 2010).

1st step: Classification

A step of impact assessment, in which environmental interventions are assigned to predefined impact categories on a purely qualitative basis (Guinee et al 2002). Also in classification is determined which of the LCI results are exclusive to one impact category and which are related to more than one impact categories (ISO 14044:2006).

2nd step: Characterization

Characterization is a quantitative step. It involves the calculation of indicator results, i.e., the conversion of LCI results to common units and the aggregation of the converted results within the same impact category. This conversion uses characterization factors. The outcome of the calculation is a numerical indicator result (ISO 14044:2006). The Eq. (1) provides an example for emissions data of how indicators for each impact category can be readily calculated from the inventory data of a product using generic characterization factors.

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$$\text{Category Indicator} = \sum_{s} \text{Characterisation Factor}(s) \times \text{Emission Inventory}(s) \qquad (1)$$

where subscript s denotes the chemical.

The emissions inventory data are in terms of the mass released into the environment-such as 1 kg-per functional unit. The characterization factors from Eq. (1), therefore linearly express the contribution to an impact category of a unit mass (1 kg) of an emission to the environment (Pennington et al., 2004). These factors are typically the output of characterization models. The factors are available in the literature, in the form of databases, as well as in available LCA support tools.

3rd step: Normalization

In normalization step, the characterization results are related to (i.e., divided) the actual (or predicted) magnitude for each impact. The aim of normalization is to understand better the relative magnitude of the environmental impacts caused by the system under study. With normalization, it becomes possible to see when for example acidification impacts caused by the studied product are large in relation to the total acidification impacts of the country where the product is produced and used (Baumann and Tillman, 2004). It is an optional element that may be helpful in, for example (ISO 14044:2006):

- checking for inconsistencies,
- providing and communicating information on the relative significance of the indicator results, and
- preparing for additional procedures, such as grouping, weighting or life cycle interpretation

Normalization transforms an indicator result by dividing it by a selected reference value. Some examples of reference values are:

- the total inputs and outputs for a given area that may be global, regional, national or local,

- the total inputs and outputs for a given area on a per capita basis or similar measurement, and
- inputs and outputs in a baseline scenario, such as a given alternative product system.

The selection of the reference system should consider the consistency of the spatial and temporal scales of the environmental mechanism and the reference value. The normalization of the indicator results can change the conclusions drawn from the LCIA phase. It may be desirable to use several reference systems to show the consequence on the outcome of mandatory elements of the LCIA phase. A sensitivity analysis may provide additional information about the choice of reference data.

4th step: Grouping

Grouping is the assignment of impact categories into one or more sets as predefined in the goal and scope definition, and it may involve sorting and/or ranking. Grouping is an optional element with two different possible procedures, either (ISO 14044:2006):

- to sort the impact categories on a nominal basis (e.g. by characteristics such as inputs and outputs or global regional and local spatial scales), or
- to rank the impact categories in a given hierarchy (e.g. high, medium, and low priority).

5th step: Weighting

Weighting is the process of converting indicator results of different impact categories by using numerical factors based on value-choices. It may include aggregation of the weighted indicator results. Weighting is an optional element with two possible procedures, either (ISO 14044:2006):

- to convert the indicator results or normalized results with selected weighting factors, or
- to aggregate these converted indicator results or normalized results across impact categories.

Weighting steps are based on value-choices and are not scientifically based. In an LCA it may be desirable to use several different weighting factors and weighting methods, and to conduct sensitivity analysis to assess the

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consequences on the LCIA results of different value-choices and weighting methods.

6th step: Additional LCIA data quality analysis

Additional techniques and information may be needed to understand better the significance, uncertainty and sensitivity of the LCIA results in order (ISO 14044:2006):

- to help distinguish if significant differences are or are not present,
- to identify negligible LCI results, or
- to guide the iterative LCIA process.

The need for and choice of techniques depend upon the accuracy and detail needed to fulfil the goal and scope of the LCA.

The specific techniques and their purposes are described below (ISO 14044:2006):

a) **Gravity analysis** (e.g. Pareto analysis) is a statistical procedure that identifies those data having the greatest contribution to the indicator result. These items may then be investigated with increased priority to ensure that sound decisions are made.

b) **Uncertainty analysis** is a procedure to determine how uncertainties in data and assumptions progress in the calculations and how they affect the reliability of the results of the LCIA.

c) **Sensitivity analysis** is a procedure to determine how changes in data and methodological choices affect the results of the LCIA.

In accordance with the iterative nature of LCA, the result of this LCIA data quality analysis may lead to revision of the LCI phase.

Limitations of LCIA

LCIA cannot always demonstrate significant differences between impact categories and the related indicator results of alternative product systems, mainly due to several reasons as:

- limited development of the characterization models, sensitivity analysis and uncertainty analysis for the LCIA phase,

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- limitations of the LCI phase, such as setting the system boundary, that do not encompass all possible unit processes for a product system or do not include all inputs and outputs of every unit process, since there are cut-offs[2] and data gaps,
- limitations of the LCI phase, such as inadequate LCI data quality which may, for instance, be caused by uncertainties or differences in allocation and aggregation procedures, and
- limitations in the collection of inventory data appropriate and representative for each impact category.

Impact assessment methodology and methods

LCIA methodology refers to a collection of individual “characterisation methods” or “characterisation models”, which together address the different impact categories, which are covered by the methodology. “Method” is thus the individual characterisation model, while “methodology” is the collection of methods. The characterisation factor, as already referred to, is the factor derived from characterisation model which is applied to convert an assigned life cycle inventory result to the common unit of the category indicator (Fig.2-13) (ILCD, 2010).

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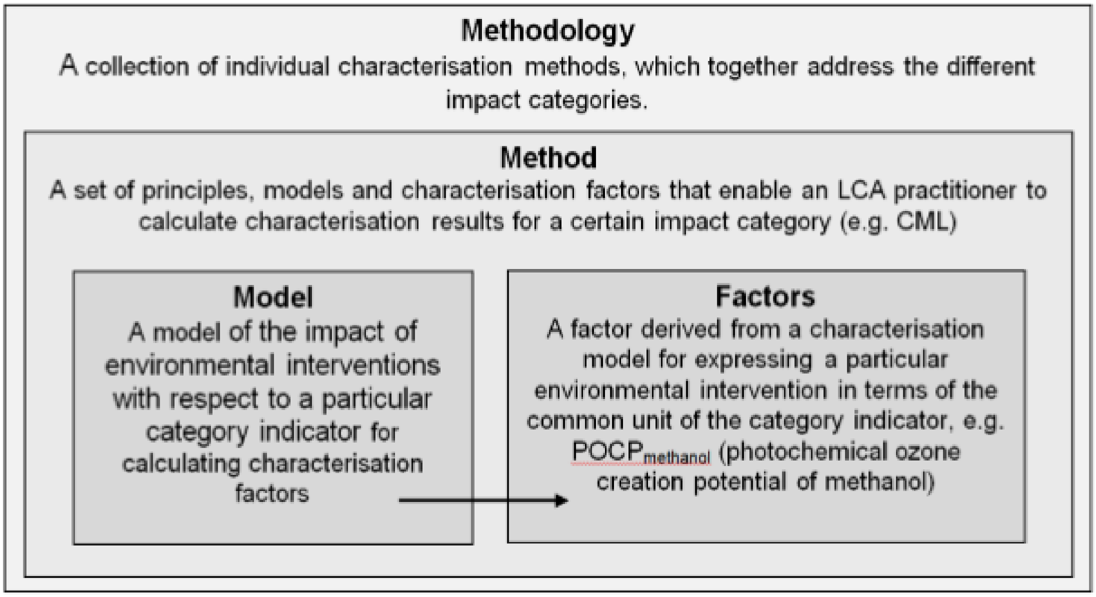
[2] "Cut-off" refers to the omission of not relevant life cycle stages, activity types, specific processes and products and elementary flows from the system model. Cut-offs are quantified in relation to the percentage of environmental impacts that is approximated to be excluded via the cut-off (e.g. "95 %" relates to cutting off about 5 % of the total environmental impact (or of a selected impact category). In practice, all quantitatively not relevant non-reference product flows, waste flows, and elementary flows can be ignored - they are 'cut-off



Methodology

A collection of individual characterisation methods, which together address the different impact categories.

Method

A set of principles, models and characterisation factors that enable an LCA practitioner to calculate characterisation results for a certain impact category (e.g. CML)

Model

A model of the impact of environmental interventions with respect to a particular category indicator for calculating characterisation factors

Factors

A factor derived from a characterisation model for expressing a particular environmental intervention in terms of the common unit of the category indicator, e.g. $POCP_{methanol}$ (photochemical ozone creation potential of methanol)

Fig. 8. Characterisation methodology, methods, models and factors (ILCD, 2010)

Within the LCIA step, two approaches of characterization can take place along the impact assessment pathway of an impact indicator, as already mentioned: midpoint approach and endpoint approach. Characterization at midpoint level models the impact using an indicator located somewhere along the mechanism but before the endpoint categories The indicator is typically chosen where it is judged that further modelling is not feasible or involves too large uncertainties, or where a relative comparison can be made without the need for further modelling (Finnveden, et al., 2009). Characterization at the endpoint level requires modelling all the way until the endpoint categories described by the areas of protection. Therefore, a category indicator, representing the amount of impact potential, can be located at any place between the LCI results and the category endpoint. Within this framework, two main schools of methods have been developed (Jolliet et al, 2003):

- Classical impact assessment methods (problem oriented methods), for example, CML and EDIP methods (referred below): These restrict quantitative modelling to relatively early stages in the cause-effect chain to limit uncertainties and group LCI results in so-called midpoint categories.

- Damage oriented methods, such as Eco-Indicator 99 or EPS: These try to model the cause-effect chain up to the endpoint or damage category, related to the different environmental areas of protection, such as human health or environmental quality. This approach often comes with high uncertainties (for example, considering the wide and dispersed endpoint implications and consequences of climate change or ozone depletion)

The midpoint approach is also known as problem-oriented approach. In the midpoint approach, the cause-effect chain starts with a specific process or an activity which leads to emissions and consequently where primary changes in the environment appear. These primary changes often occur early in cause-effect chain and are often chemical and physical changes. For example, in case of studying the primary effects in the climate change, changes in concentrations of gases in the atmosphere or changes in infrared radiation are noticed. At this point, the LCI results represent contributions to different environmental problems such as global warming or stratospheric ozone depletion. Later on, in the cause-effect chain, often biological changes occur that are represented in damages on Eco systems, human health and resources. For example, one of the damages to human health resulting from stratospheric ozone depletion would be an increase in skin cancer. This is called an endpoint approach. Therefore, an endpoint approach is known as damage-oriented approach. The Life Cycle Initiative for LCIA proposed to utilize the advantages of both approaches by combining midpoint and endpoint methods under a common framework (Jollliet et al., 2004)

Today, several LCIA methods are available, and there is not always an obvious choice between them. In spite of resemblance between some of them, there can be important differences in their results which depend on choice of LCIA method. Recommendations from UNEP/SETAC Life Cycled Initiative and ILCD help to identify the best practice for LCIA within the framework lay out by the ISO standards (Finnveden, et al., 2009).

Traditional characterisation methods are examples of midpoint modelling. Representatives of this midpoint or problem oriented LCIA methods are:

- CML 2002: The CML method, first developed in 1992 (Heijungs et al., 1992) by the Centre for Environmental Studies (CML), University of

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Leiden in Netherlands, has been updated to the baseline CML 2002 (Guinée et al., 2002).

- TRACI: The Tool for Reduction and Assessment of Chemical and other environmental Impacts (TRACI) was developed by the US Environmental Protection Agency (Bare et al., 2003)
- EDIP 2003: Environmental Design of Industrial Products (Hauschild and Potting, 2005) is a Danish LCA methodology that is presented as an update of the EDIP 97 methodology.

An alternative school of characterisation modelling represents the endpoint or damage oriented LCIA methods. Examples of these methods are:

- Eco-Indicator 99: The Eco-Indicator 99 has been developed top-down, starting from weighting and from there developing damage models for the most important impact categories (Goedkoop and Spriensma, 2001).
- EPS 2000: Environmental Priority Strategies is a damage oriented method with top-down development (Steen, 1999).
- Eco Scarcity 2013: The “ecological scarcity” method (also called Ecopoints) is a follow up of the Ecological scarcity 2006 and the Ecological scarcity 1997 method (Frischknecht R., Büsser K.S., 2013).

Also there are the methodologies that combine midpoint and endpoint approaches such as:

- IMPACT 2002+: Impact Assessment of Chemical Toxics, is an impact assessment methodology originally developed at the Swiss Federal Institute of Technology - Lausanne (EPFL). The present methodology proposes a feasible implementation of a combined midpoint/damage approach, linking all types of life cycle inventory results (elementary flows and other interventions) via 14 midpoint categories to four damage categories
- ReCiPe 2008: The Recipe methodology development was conducted by the cooperation of many developers working within the LCA field (RIVM, CML, PRé Consultants, Radboud University Nijmegen and CE Delft). This methodology is considered as a follow up of the CML 2002 and the EI99 methodologies. ReCiPe comprises two sets of impact categories with

associated sets of characterization factors. At the midpoint level, 18 impact categories are addressed. At the endpoint level, most of these midpoint impact categories are multiplied by damage factors and aggregated into three endpoint categories.

- LIME and LIME 2: These methodologies were developed in Japan within the framework of an LCA national project funded by METI/NEDO. LIME method was developed for quantifying the environmental impacts that are induced by the incidents of environmental loading in Japan, combining the two families of methodologies, midpoint and endpoint. LIME 2, a version of LIME, developed to encompass the uncertainties of all of the damage factors are measured into the results, improving their reliability.

Other LCA based methodologies are: a) the Ecological Footprint, which has emerged as the world’s premier measure of humanity’s demand on nature, specifically on land use, b) the USEtox methodology, which is a different kind of LCIA since it deals with the development of characterization models for human and ecotoxic impacts, c) the Eco system Damage Potential (EDP), an LCIA methodology that also deals with specific life cycle impact categories, d) the Intergovernmental Panel on Climate Change (IPCC), an LCIA methodology the leading international body for the assessment of climate change, and many other.

Each of these methodologies constitutes a database of substances and materials which are used in the LCA studies. Specific software tools are used to deal with the LCIA methodologies. There is a number of commercially available software for LCA, often combined with necessary databases for setting up the inventory data. Some of the most famous software tools are: GaBi (Pe International, Germany), Sima Pro (PRé Consultants, Amersfoort, NL), Gemis, and Bees. The use of such software tools requires much training and profound knowledge of LCA. However, in most cases, an LCA practitioner does not execute in details the impact assessment step (characterization, normalization and weighing), as it is done efficiently with the help of the software tools and the associated LCIA methodologies

3. Good practices

3.1. Definition of Good Aquacultural Practices

Good aquacultural practices (GAqPs) are activities, procedures, or considerations that maximize environmental and economic sustainability, product quality and safety, animal health, and worker safety, while also minimizing the likelihood of a disease outbreak on the farm. Similar terms such as best management practices (BMPs) and good agricultural practices (GAPs) are often used to express the same concepts, which has caused confusion within the aquaculture industry. In this report we use the GAqP designation. Good aquacultural practices can be generic or specific, depending upon the application or use. Generic GAqPs often are used to convey concepts or practices for wide application, with individual facilities then using these to develop sitespecific GAqPs. In some localities, BMPs have become regulatory in nature. The good aquacultural practices described here are not intended to promote any regulatory rule, but rather to describe general principles, concepts, applications, and considerations to enhance the sustainability of both individual aquaculture producers and the industry as a whole. These GAqPs are voluntary and may be adapted and adjusted as appropriate for individual situations and conditions. Adjustments might be made because of factors such as production species, systems used, location, and even potential markets.

Main objective is the promotion of a sustainable aquaculture that creates growth and jobs and contributes to food security and supplies. The Good Practices should further aim at:

a) improving the competitiveness of the aquaculture industry and supporting its development and innovation;
b) reducing the administrative burden and making the implementation of law more efficient and responsive to the needs of stakeholders;
c) encouraging economic activity;
d) diversification and improvement of the quality of life in coastal and inland areas;
e) Integrating aquaculture activities into maritime, coastal and inland spatial planning.

The Guidelines on Aquaculture ensure that these objectives will continue to be pursued, by providing updated strategic guidance. Furthermore, they

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contribute to achieving the objectives drawn under the new policy priorities such as the Farm to Fork Strategy and the Green Deal, in particular in terms of social and environmental sustainability and climate change adaptation and mitigation efforts.

According to the results of the ECO-FISH project, some general rules are produced:

- Seafood farmers should focus on improving the general management of their production systems, with a specific attention to the management of nutrients, the water management and the choice of adapted and optimized aquafeed (different system components and Improving feed production). Some technologies have a great potential to improve environmental impacts, such as polyculture, or low energy systems.
- Policymakers should base their regulations on LCAs to improve the Environmental impacts of existing and future aquaculture systems. Such regulations should be backed-up by nationwide and/or sector wide LCA studies to identify hotspots. Such regulatory efforts should be complemented with initiatives that sensitize the public to sustainable seafood production, which may create market-driven call for more sustainable production schemes; the use of LCA-based ecolabelling can help in such initiatives.
- Seafood technology/system developers must systematically include life cycle assessment to assist them in finding as environmentally sustainable systems/ technologies as possible when working on improving productivity. As part of our review, environmental hotspots were identified for a number of specific technologies and systems; these may also serve as basis to improve existing systems and develop new ones
- Consistent and detailed guidelines on how to apply the LCA methodology to aquaculture systems should be developed to improve the consistency and comparability of studies. To reach that aim, the transparency in reporting the scope and inventory phases of LCA studies should be a priority for LCA practitioners. LCA method developers should additionally extend the range of existing impact categories to include new impact categories specific to the aquaculture sector, for example enabling assessing the reduction of antimicrobial

resistance to unveil potential environmental trade-offs with commonly assessed categories of impacts.

3.2. Fields for applying Good Aquacultural Practices

Facility siting and design

Proper site selection takes into account environmental resources as well as access to industrial infrastructure such as roads, airports, and reliable electrical power. Environmental parameters focus on water resources (typically surface water or groundwater) to supply aquaculture operations as well as water discharge. Surface water and groundwater sources for incoming water should be analyzed for water quality and for chemistry parameters appropriate for the culture species. Sampling should be conducted periodically over a year’s time to evaluate seasonal fluctuations that can affect both quality and quantity. Historical data should be obtained going further back in time to determine impacts from droughts. Topography has a significant effect on surface water, directly impacting runoff and drainage patterns. If a facility is downhill or downstream from agricultural or industrial activities, they may become an intermittent source of water contamination from fertilizers, manure, pesticides, or other chemicals. Thorough testing of water quality is essential to determine whether contamination risks exist. Aerial spraying is also a potential source of direct contamination from adjacent agricultural activities and is independent of topographical layout. Specific to pond site selection is slope, soil composition, and depth. Ponds are designed to hold water, so unless expensive liners will be utilized, soil clay composition should be a minimum of 20 percent to ensure water retention. In addition, soil quality such as pH and organic matter concentrations are important. Ideally, soils with a pH of 6-8.5 are best, requiring minimal treatment. Soils with high organic matter should be avoided because they can create high oxygen demand and release toxic nitrogen compounds.

The site selected for an aquaculture operation should be one where there is no danger that the facility will be flooded and one that is a reasonable distance from other industrial or agricultural activities that could adversely affect the type of aquaculture production system being built. For example, an aquaculture pond facility should not be located adjacent to agricultural land that is regularly treated with pesticide unless there is a buffer zone or at least an agreement with adjacent landowners. For extensive outdoor production, soil should be analyzed to ensure that it is appropriate (such as having adequate clay content for ponds) and that it is not contaminated with chemicals from previous land use. The facility should be designed to minimize access from one production phase to another. That is, if hatchery or fingerling production will occur, these areas should be sited and designed to minimize exposure to other production units. This includes physical separation, worker access and flow, and even security considerations as appropriate. Facility designs should be scaled appropriately to conservatively meet production goals without pushing system or species-specific production densities. Further, waste management systems/facilities should be sized to meet and exceed anticipated waste volumes. Both production and wastewater treatment systems should be inspected routinely and maintained to ensure proper operation, and promptly repaired as needed. Depending upon the type and intensity of the production system, some form of emergency back-up power is required. The more intensive the production system or the greater the dependence upon electricity, the larger and more reliable a back-up system needs to be. Auto-start and auto-transfer for intensive operations are a must. When construction is completed, all exposed soils should be stabilized to minimize erosion.

Production/Growout

Good aquaculture procedures are designed to maintain optimal production parameters throughout the culture period to maximize production performance as well as animal health, safety, and welfare. In production ponds, minimum oxygen levels and other water-quality parameters (ammonia, pH, and nitrite) – all of which are species-specific – should be maintained. Ponds should be kept destratified with aerators as needed. Research has demonstrated importance of adequate aeration to maintain a minimum level of dissolved oxygen. Maintaining adequate dissolved oxygen allows fish to continue feeding and results in better growth; which has implications for crop harvest cycles and cash flow. Feeding should occur in the morning after dissolved-oxygen levels from photosynthesis begin to rise, and if two feedings per day are applied, the

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second feeding should occur at least three hours before sunset to allow for oxygen levels to rebound after feeding activity. If dissolved-oxygen levels are running low overall, the second feeding should be eliminated until levels improve. If levels continue to be problematic, the first feeding can be reduced or temporarily eliminated as well, while pond management techniques such as continuous aeration and pond flushing are applied. Stressed animals should never be graded, harvested, or otherwise handled, as this additional stress is generally sufficient to cause a secondary disease outbreak or mortality. Every three to five years or so (depending on species, production levels, and organic matter buildup), it is important to rotate ponds temporarily out of production, drain, dry, and disk hydrated lime into the bottom soils to help maintain pH, and oxidize organics that accumulate during production phases. Rates of 1,500-2,000 pounds of hydrated lime (calcium oxide) per surface acre are recommended for sterilizing pond bottoms. Developing a biosecurity plan is essential for all types of production systems. Care should be taken to minimize cross-contamination between ponds or tanks by sanitizing harvest gear such as seines, waders, nets, and hauling tanks; personnel access should be limited.

Animal health

The goal of the producer is to manage the system to reduce the risk of fish health problems. The best approach is to use good animal husbandry and animal health GAqPs. A producer must develop a biosecurity plan that meets the needs of his production system. While significantly affected by facility biosecurity, animal health has additional GAqP components relating to husbandry. The critical factor to fish health is water; water quality always should be maintained at an optimal level for the target species. When a facility has poor water quality parameters, such as high ammonia levels, this will increase animal stress and can result in disease outbreaks. For example, Streptococcus outbreaks in tilapia facilities are often linked to poor water quality. It is imperative that water quality be monitored frequently in accordance with the type of production system used. Should a water quality deviation occur, it must be corrected as soon as possible. The reason for such concern with water quality is that the environment is one of the three components of the Fish Health Model (FHM). The FHM has three basic components: the host (fish); the environment (water); and the

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pathogen. It is the interaction of these three components that results in a disease outbreak. Fish pathogens may be present but not cause a disease outbreak. It generally is not until the aquatic environment deteriorates (poor water quality) that the pathogen can infect the host and cause disease. Thus, biosecurity and water quality management are critical GAqPs for maintaining animal health. Animal health is also maintained by minimizing overall stress in the production process. To this end, GAqPs include routine monitoring of animal health to develop baseline health indices (such as relative weight, skin and gill health, internal organ appearance, etc.) and then routine testing to compare fish with that baseline. Deviations can indicate the progression of a disease, poor water quality, nutrition or feeding issues, and more. Another animal health GAqP is to develop a relationship with a qualified aquatic veterinarian. The veterinarian should make periodic site visits and assist in developing a site-specific health plan. If there is a disease outbreak, there are just a few antibiotics and one paracide (formalin) approved by the FDA for aquaculture. Therefore, it is absolutely essential that the correct treatment is chosen, that the proper dosage is used, and that proper withholding periods are observed before products are sold for human consumption. A veterinarian can help with these tasks, too. All chemicals and antibiotics must be kept in their original containers and stored in a cool, dry place. Always follow the instructions on the label. A significant GAqP relating to animal health is the use of a fish health management plan. The plan should describe the predetermined steps a producer will take if fish begin to die unexpectedly. When fish are dying, it is critical to identify the cause correctly before the disease spreads to other systems and/or facilities in the area. Once identified, predetermined corrective actions must be implemented quickly. Fish may need to be examined by a veterinarian.

Cleaning and Sanitation

Equipment used in the facilities to handle or move fish should always be dipped in disinfection vats prior to reuse. Equipment should never be used in multiple areas of the facility. Fishnets, buckets, and other pieces of equipment that are used in a hatchery should never be used anywhere else. Likewise, equipment that has been used in the growout section of the facility should never be allowed within the hatchery or juvenile production

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areas. Animal and Pest Control Good aquaculture procedures for animal and pest control involve exclusion, control, and eradication measures where appropriate. In pond production, the more significant animal vectors are birds and fourlegged animals. For bird control, a combination of scare tactics and lethal depredation techniques are often the most effective (depredation requires permits, usually from a state game and fish agency). Terrestrial animal control usually incorporates facility fencing, and sometimes pond fencing. For rodents, perimeter traps close to habitat may be effective. Recirculating aquaculture systems are typically housed in buildings, so the structure itself is usually effective to exclude most birds and terrestrial animals. However, rodents, roaches, and other pests tend to be more concentrated around RAS structures due to the attraction of feed and fish. Therefore, effective plans to operate and maintain rodent traps are important, as is proper chemical pest control for roaches and such. Great care must be taken with chemical control to assure that chemicals or sprays do not come in contact with feed, water, or production equipment. Emphasis on pest control is required in the feed-storage area.

Feed management

Feed management GAqPs range from nutritional composition to storage and application. Aquaculture feeds come in many formulations, sizes, and types. It is important to feed the correct nutritional composition, feed size, and feed type (floating, sinking, or slow-sink) to match the species, life stage, and production system being used. Feed rations are affected by water quality parameters such as dissolved oxygen and temperature. For outdoor extensive systems, these two parameters can vary widely and need to be closely monitored and adjusted. In indoor intensive systems, these variables are controlled by the system and come into play only when there is a system malfunction. Fish can be fed manually or with demand and auto feeders. Feed equipment should always be kept clean and in proper operating condition. Animals should never be overfed; an appropriate feeding level is about 80 percent of satiation daily. Splitting a daily feed ration into several smaller feed amounts and feeding several times a day can enhance fish growth and feed conversion ratios and minimize the water quality fluctuations associated with increased oxygen demand during and after feeding, as well as spikes in nitrogenous wastes.

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Feeds should be stored with their labels, which include dates of manufacture, feed mill ID, and lot number. Inventory should be rotated back to front and feed should be stored in controlled environments whenever possible. Feeds should be used before their expiration dates, generally about 3 months from the manufacture date. To maximize shelf life, feed should always be stored off the ground, away from contact with walls, with air space between pallets, and in an area with appropriate animal and pest control. Feed on pallets should never be stored more than one pallet high to avoid crushing the pellets into unusable fines and to prevent worker injury from falling or shifting bags. Wet feed should never be used or stored because it will rapidly become moldy and spoiled. Moldy feed can cause rapid mortality in fish or compromised immunocompetence because of the toxins associated with molds. Because feed costs may be more than 50 percent of the total production cost, proper feed management is critical to all production facilities.

Harvesting and handling

Good aquaculture practices for pre-harvest and harvest focus on maximizing the quality of the product and minimizing stress on the animal. Prior to harvest, feed should be withheld for a predetermined number of days to allow for gut evacuation. This enhances the shelf life of the product and reduces the chance for off-flavor in the product due to leaching from the gut. It is also critical to make sure all harvest equipment is in proper working order, that containers for receiving the product are properly cleaned and sanitized, and that sufficient high-quality ice is ready to properly chill-kill the product. Chill-killing in water/ice slurry is critical to rapidly lowering the core temperature of the harvested product, which reduces spoilage. Once harvested, the product must be kept below 38 °F (3.3 °C) before, during, and after processing. Proper records must be kept from production through sales.

To minimize bacterial contamination, all surfaces and utensils that might come in contact with the product must be cleaned and sanitized before processing begins and after each batch of product is processed. This includes items such as utensils, knives, totes, tables, cutting boards, ice makers, ice storage containers, hands, gloves, aprons, trucks, and nets.

Sweeped or rinsed surfaces are important to remove soil and other matter and then wash and rinse the surface with the appropriate cleaning agents. It is just as important that no non-food grade chemicals and no material hazards (e.g., a fractured piece of metal from a knife) come into contact with the product.

HACCP is a systematic preventative approach for ensuring that each of the processing, packaging, and storage steps do not compromise the food safety of the product. Processing GAqPs include rapid cooling, rapid freezing, and temperature control during storage. The product in the middle of the mass may not freeze for 24 hours and will compromise the rest of the product. Products should be stored at a temperature of 32 °F (0 °C) or colder unless they will be sold immediately. Seafood stored at 32 to 40 °F (0 to 4 °C) will degrade within a few days. Shelf life is dependent on the product type, how it is packaged, and how it has been handled during storage. Fact sheets are revised as new knowledge becomes available. Fact sheets that have not been revised are considered to reflect the current state of knowledge.

To extend shelf life, storing product at less than -10 °F (-23 °C) in freezers without defrost cycles. Minimizing risk during transportation by ensuring that the transportation vehicle is clean. The truck should be cleaned and sanitized between uses, especially if the truck has been used previously to transport other food products such as eggs, raw meat, or poultry. The product should never be transported in a truck that has been used previously to carry live animals, manure, or garbage. During transportation, the product should be properly packaged and must be kept frozen or cool to maintain product quality and safety. Digital temperature loggers can be used to track the temperature of the product throughout the processing, packaging, storage, and transportation steps. Tracking temperatures is a critical part of maintaining good records and will help ensure that the food products are safe and of the highest quality.

Business Planning

While business planning is not traditionally mentioned in the discussion of good aquaculture practices, experience has demonstrated that it is a crucial step in the development and management of a successful aquaculture

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business. A large portion of aquaculture ventures that fail, do so as result of financial challenges; cash flow in particular. It is essential to develop a business and management plan for the business. This is equally true for both new ventures and existing businesses. The process of developing a thorough business plan requires careful consideration of all aspects of the business, including production, marketing, and capital. Preparation of financial statements is crucial, and it is best to be conservative when projecting yields and revenues. There are various tools available to guide and assist with the development of business plans. The business plan should be regarded as a living document and should be revisited at least once per year to assess business performance and make any adjustments to the plan. Making small changes and adjustments in the business over time can help to improve the long term position of the business and can potentially help to avoid having to make large investments or costly changes all at once.

4. Measures to improve the environmental footprint of aquaculture

Adopting a life-cycle approach allows examination of the whole supply chain, or most of it, when trying to identify areas for improvement. In theory, there is a wide range of measures that could be used to reduce the environmental footprint (EI) of aquaculture. The challenge is to identify those measures that provide mitigation in ways that are technically effective, economically efficient, and acceptable to producers and consumers. Although providing a comprehensive review of possible mitigation measures is beyond the scope of this report, some examples are presented below, along with discussion of how the model could be developed to evaluate such mitigation measures

Reducing emissions from feed material production

The emissions arising from the production of feed materials (not including their subsequent transport and blending) can be reduced by: (a) reducing the EI of individual feed materials, and / or (b) substituting high EI materials

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for lower EI materials. There is a wide range of ways in which the emissions from feed material production can be reduced. MacLeod et al. (2010) identified 97 measures, such as changing aspects of agronomy and nutrition management, which could reduce on-farm crop and soil emissions. Further reductions may be achieved by reducing the losses of feed material that occur post-production, in storage (particularly in warm, humid climates), processing and transport. However, uptake of these measures is often beyond the control of those directly involved in the aquaculture industry. Replacing a high EI feed material with a lower EI alternative can reduce the feed emissions. However, this approach raises questions such as:

- ✓ What are the effects of the change in ration on fish performance?
- ✓ Is there adequate supply of the substitute feed material?
- ✓ What does it cost?
- ✓ What would the effect be of changing the ration on the quality and nutritional value of the fish produced?

Some classes of feed materials with similar nutritional and emission profiles include materials which are relatively interchangeable, for example carbohydrate-supplying raw materials such as wheat and maize. However there are exceptions, for example maize is not used for striped catfish feeds because of the pigments which are transferred to the flesh. However, in reality, price and availability currently have a much greater influence on feed formulation than does EI.

Reducing feed mill energy use emissions

There is a wide variation in the rates of energy use in feed mills per unit of feed produced. While some variation may be due to differences in the way energy consumption is recorded, the wide range suggests there is scope for further investigation of the causes of the variation, and thereby identifying ways of improving energy efficiency. Such improvements could be achieved by training operators in more efficient management of the feed mills, by setting and meeting better operating targets, and through the selection of more efficient equipment when establishing or upgrading feed mills.

Substituting high EI fuels for lower EI alternatives could also be used to reduce feed mill energy use emissions. For example, replacing coal with biomass should reduce emissions, but care should be taken to ensure the biomass production is not displacing food/feed crop production, or inducing direct or indirect LUC

Improving efficiency of feed management and feed conversion

Feed management and feed conversion were recognised as key areas requiring improvement in aquaculture. There is a strong financial aspect to this, as more efficient use of resources should bring increased profitability. In addition, as feed is the biggest source of GHG, achievements in reducing overall eFCR should have a beneficial impact on reducing the total EI. In recent years FCR has generally decreased in aquaculture, through improved nutritional knowledge and improved farming methods (Bureau and Hua, 2010). However, more can be done to improve the current commercial situation.

Optimising feeding

Feeding may be made more efficient by identifying and using more appropriate nutritional targets for the species, and using better quality raw materials. However, these changes will also increase the unit price of the feeds, which may make them

unaffordable for some farmers. More nutritional studies are required on the target fish species to support the goals presented by NRC (2012). Such studies would investigate the protein and energy requirements of the fish, and their amino acid needs. Feeding individual amino acids in excess of requirement results in increased NH3 excretion, whilst under-supply increases the consumption of feed by the fish to achieve the amount required for growth (Bureau and Hua 2010). Field trials of feeds closer to the nutritional goals of the fish are required to quantify the economic and EI impacts of the changes. Through altering the FCR and reducing waste in the ponds, fish health and performance may improve, so balancing the cost of production. If positive effects are found and are demonstrated to farmers, then practices will change.

Updating the companies on the latest knowledge of the nutritional requirements for the species will enable them to choose whether to alter the feed, in decisions driven by market forces. The use of appropriate feed

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additives should also be considered. Many feed raw materials used for the three species in this survey are relatively poorly digested by the fish. In particular, phytate in the raw materials interferes with protein and phosphorus digestion, increasing the feed required to achieve a certain growth. The use of the enzyme phytase to break down the phytate improves nutrient digestibility, (Debnath et al., 2005).

Feed management

How the feed is presented to the fish has a large impact on the total eFCR (Robb et al., 2013). If the feeds are not effectively spread across the ponds, many fish will not eat enough feed to grow efficiently. If insufficient feed is given, fish will eat but will use a greater proportion of the feed for maintenance of energy rather than growth. If too much feed is given, which is rare with floating feeds, but can easily happen with sinking feeds, feed is wasted. Timing and number of meals per day are also important for each species (Robb et al., 2013). Fish are mainly fed during the day, when the oxygen content of the water is typically higher than at night. However, feeding late in the day

increases the risk that the oxygen content in water will naturally decrease whilst the fish are still trying to digest the feed, making the process less efficient. Fish activity around feeding further decreases the oxygen content in water, again reducing the efficacy of feed digestion and absorption. More training on feed management is required for farm managers and workers, to ensure that the fish are presented with the correct amount of feed at the optimal times.

Water quality

Fish need oxygen to digest the feed efficiently. In ponds, there is often a risk of low oxygen concentrations, especially with striped catfish, where farm water quality is typically very poor (Lefevre et al., 2011). Increasing water exchange or adding aerators to the ponds may help to increase the dissolved oxygen in the water, enabling the feed to be used more efficiently. Depending on the specific measures undertaken, this addition may lead to changes in energy costs and emissions. The costs and net GHG effects of different water quality measures should be investigated to identify the most cost-effective options.

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Improving the EI by improving fish health

Fish disease leads to direct farm level losses from mortality, a lowering of the efficiency of the production, and a reduction in output quantity and/or quality. Reducing disease could, in principle, lead to significant reductions in emissions intensity, for example by improving the feed conversion ratio of individual animals, or reducing losses from mortality. Improved fish health could be realised through better water quality management, more nutritious feed, appropriate fish stocking densities, as well as through implementation of effective biosecurity measures and appropriate use of medicines. Although the inter-relationship between these factors is obvious, the optimal points are not yet defined or communicated to the farmers.

Reducing on-farm N_2O

The N_2O emissions from ponds can be reduced by either reducing the amount of N available for conversion to N_2O, and/or reducing the rate at which the surplus N is converted to N_2O.

Reducing surplus N

Improving the overall nutrient use efficiency (NUE) of the system will lead to reduced amounts of surplus N per kg of fish produced (i.e. N inputs not converted into tissue by the fish), which will in turn reduce the N_2O emissions - assuming the rate of conversion of N to N_2O is constant. The NUE could be improved in a number of ways, such as:

- Decreasing the percent of uneaten feed (by manipulating the amount, timing,

distribution, particle type and size).

- More closely matching the feed N content to the fish requirements (particularly amino acid content).
- Making the N in the feed more available (for example through the use of phytase).
- Closer matching of synthetic and organic N application to pond requirement.

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It has been argued that switching from conventional aquaculture to alternative aquaculture systems, such as those using aquaponics and bioflocs technology, could also reduce N_2O by increasing the amount of N retained in biomass (Hu et al., 2012).

Reducing the N2O EF

The rate at which N is converted to N2O in the ponds is a function of parameters including concentration of N compounds such as NH_3, dissolved oxygen concentration, pH, water temperature, salinity, concentration of toxic compounds such as H_2S, and the presence of other aquatic organisms. Hu et al. (2012) concluded that "the most common method to control N_2O emission from aquaculture is to keep the system under optimal operating conditions, such as appropriate pH and temperature, sufficient DO, good quality feed, etc.". However, Hu et al. (2012) also note that further work is required to develop the "comprehensive understanding of the production mechanisms of N_2O in aquaculture systems" required to develop recommendations for N_2O mitigation measures.

Evaluating measures to improve the EI of aquaculture

To identify the most cost-effective (CE) mitigation measures, it is necessary to quantify: (a) the emission reductions arising from the measures, and (b) the costs of implementing them. The ease with which the CE of a measure can be quantified is partly dependent on the nature of the measure. Some measures are relatively discrete, which makes quantifying the CE straightforward. For example, the mitigation impact and cost of switching from using coal to gas can be readily quantified using published emission factors and fuel prices. In contrast, many measures can have systemic effects, and/or unintended consequences, and quantification of their CE is more challenging. For example, substituting higher EI feed materials with lower EI feed materials can reduce feed emissions. However, if the substitute feed material has different nutritional properties, these may affect the physical performance of the fish, leading to an increase in FCR and N excretion, and consequent increases in emissions (Fig. 9)

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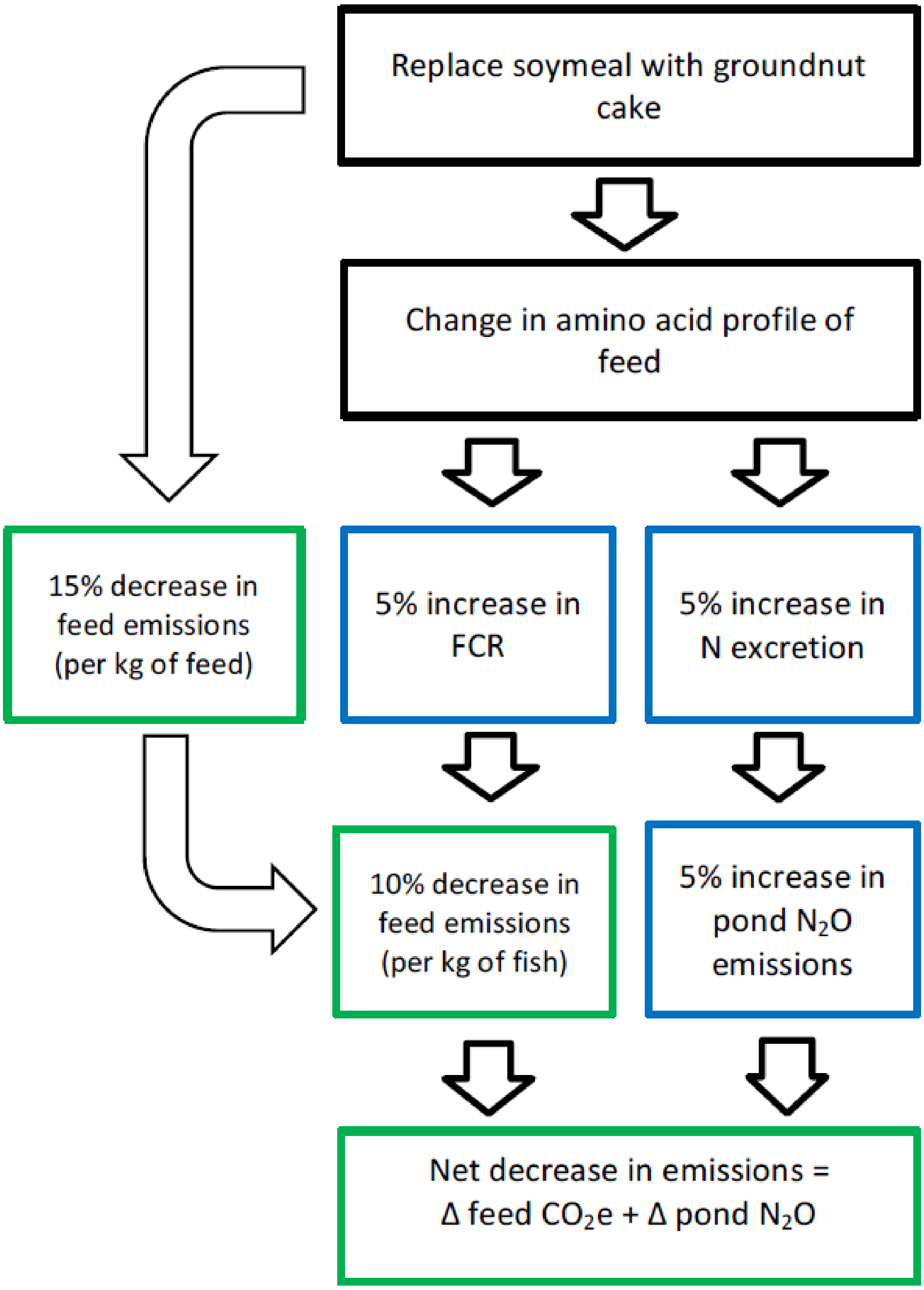

Fig. 9. Systemic effects of replacing a high EI feed material with a low EI feed material (green boxes indicate emission decrease, blue boxes emission increase)

An additional example of a systemic measure is increased pond aeration, which would decrease the feed emissions and pond N_2O, while increasing the emissions arising from on-farm energy use (Fig. 10). For changes to be implemented in the field, there have to be some economic benefits, to the

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feed mill and/or to the farmer. Therefore, to identify the most cost-effective mitigation options, quantification of the effects on emissions and costs of implementation is required. Cost-effectiveness analysis is especially important for striped catfish, where the low market price has already made farmers struggle to continue in business.

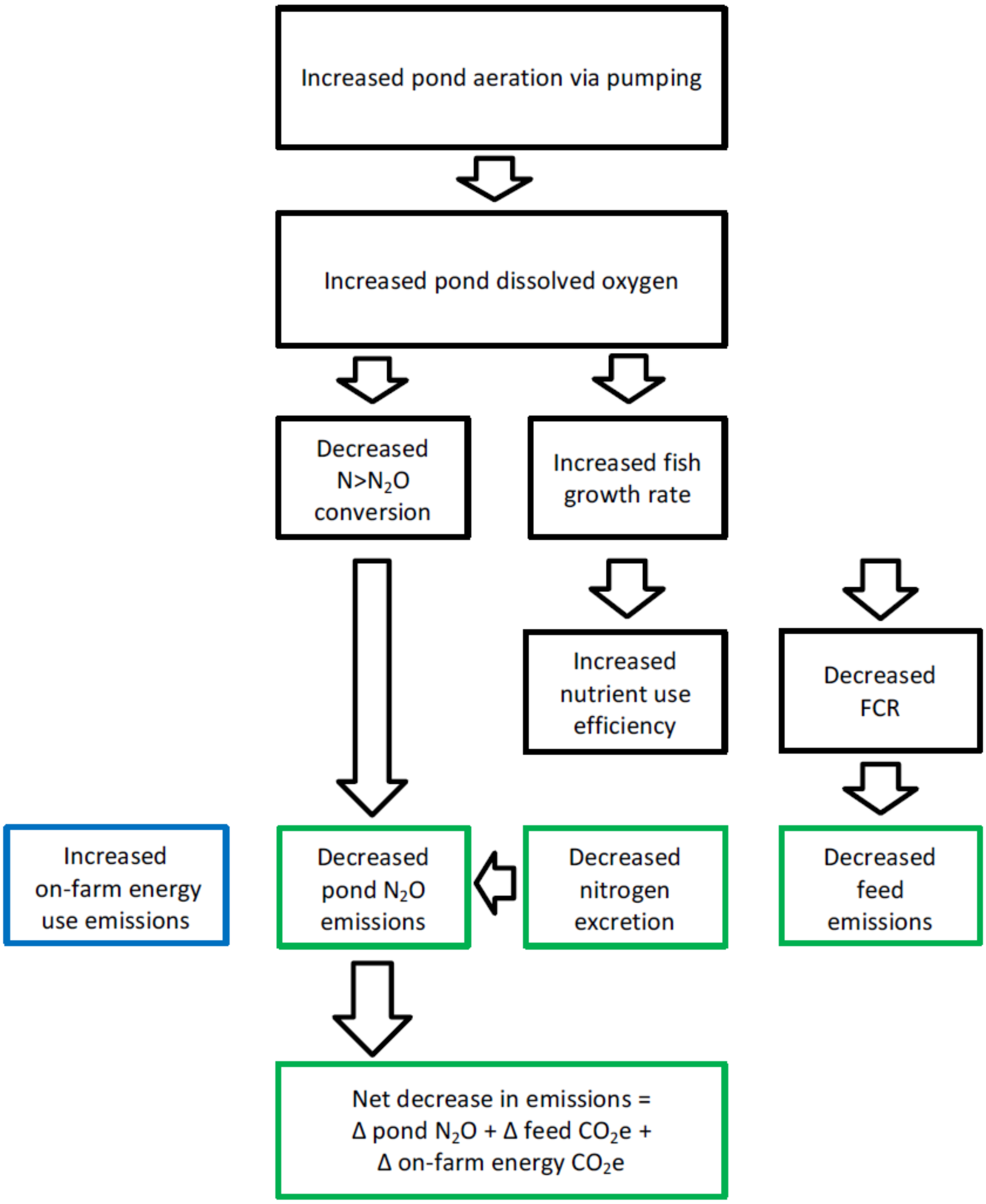

Fig. 10. Systemic effects of increasing the pond dissolved oxygen content through increased aeration (green boxes indicate emission decrease, and blue boxes emission increase)

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5. Policy Recommendations

5.1 Policy Recommendations

From the evaluated results it becomes obvious that the main area for improving the environmental im-pact of fishing lies in the catch phase and in particular in the operation of the fishing vessel. While the political solution so far has been to support investments in new engines, argues that more efficient engines are likely to cause an increase in fishing activity, which in turn results in less fish. Less fish leads to another increase in fishing activity. A positive feedback loop evolves. Further significant improvements can be made in packaging: The use of different packaging material can lead to a reduction of environmental impacts. To reduce impacts on biological resources, strict fishing quotas should be established and adhered to. In addition, sustainable management of fish stocks could reduce the amount of energy used per kg of landed fish as low catch rates are linked to high fuel consumption. High fuel prices might have a positive effect on fuel consumption.

Aquaculture’s environmental impacts can be lowered by a change in feed composition: The substitution of animal by-products by vegetal ingredients reduces total environmental impacts of fish feed. One should keep in mind that fish meal and oil are mainly by-products from other industries. Abandoning the use of these ingredients would reduce environmental impacts of fish feed, but it is not clear if this leads to an improvement on a larger scale: The available quantity (and environmental impacts) of these by-products is defined by the production of other products not by the demand created by fish feed production as the clear majority of fishing targets edible fish. It would not be any better to waste these by-products.

Another option is to improve feeding technique: The amount of feed needed per kg of salmon pro-duced (FCR) varies significantly in different regions. Another risk created by aquacultures is escaping fish. Therefore regulations need to be introduced to protect natural habitats.

5.2 Consumer Recommendations

From the consumer perspective, two recommendations can be made in regards to choices made at the supermarket: Firstly, when deciding between fish and meat, the analyses with the GWP method suggest that

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some types of fish from high-sea fishing are a less harmful choice for the environment than beef and veal. However, this cannot be generalized, as environmental impacts of some fish species are considerably higher. For some more expensive types of fish such as shrimps, flatfish or delicacies such as the Norway lobster, the GWP can rise above 30 kg CO2-eq per kg of fish. This is due to economic allocation.

Aquaculture is sometimes praised as an environmental friendly alternative to high-sea fishing or land based animal husbandry. Calculations reveal that it is for salmon in the same range as high sea fish with regard to GWP. Its downside is eutrophication and disturbance of natural habitats. The use of vaccines and antibiotics worsens environmental impacts of farmed salmon. In regards to eco-points, salmon performs considerably worse than high sea fish and most meat products.

Thus, there’s no clear cut answer to the question of whether an environmentally concerned consumer should rather buy meat or fish. The environmental impacts of fish are quite variable depending on the type of fish and fishery. From an environmental point of view a vegetarian diet is more preferable than eating fish and meat.

Finally, consumers should be aware that neither the eco-scarcity nor the GWP method adequately addresses the severe environmental consequences of overfishing or sea floor damage caused in particular by bottom trawl fishing vessels. For consumer advices one should consider e.g. recommendations by the WWF concerning types of fish which are so far not endangered by marine overfishing.

5.3 Research Recommendations

Apart from consumer and policy recommendations some recommendations for further research can be given. This study shows that several aspects are not implemented in the LCA methodology so far. The most significant aspect concerning fishery is overfishing and the destruction and disturbance of natural habitats. Further development in LCA should address these problems as they resolve around the main problems towards a sustainable fishery. A starting point might be to check whether fishing quotas are adhered to or not (provided that current fishing quotas are considered as sufficient means of creating a sustainable

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fishery). Coping with seabed disturbance is another point that needs to be taken into account in more detail, especially when analysing trawling.

Another aspect that has been mentioned several times before is the formation of secondary dinitrogen oxide from nitrogen emissions into the ocean. So far there seems not to be much scientific knowledge about it.

Furthermore, the amount and influence of emitted anti-fouling paint is uncertain. The share of paint that flakes off the ship is hard to quantify and its fate and behaviour in the environment is highly un-certain.

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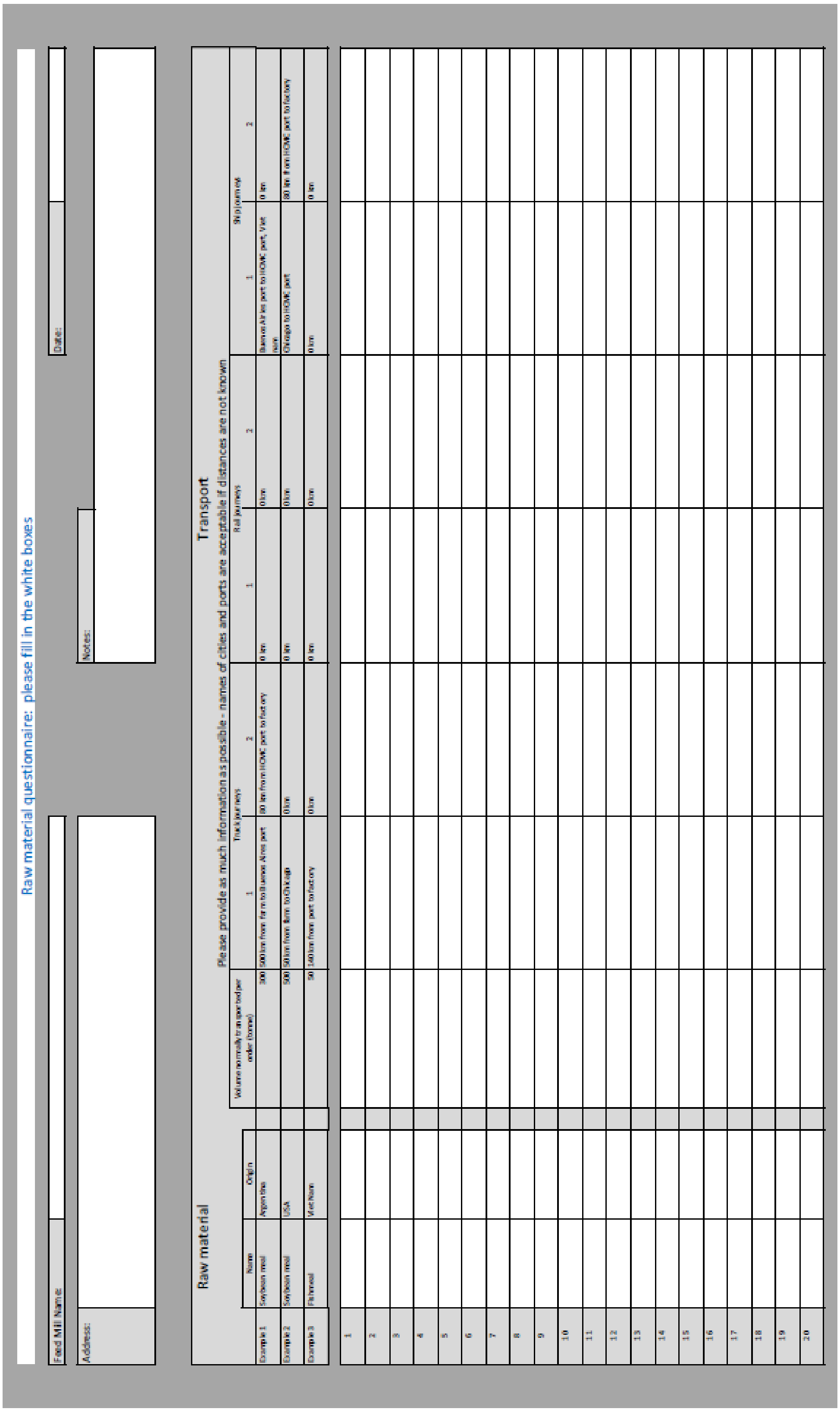
Appendix

Raw material questionnaire



Raw material questionnaire: please fill in the white boxes

Feed Mill Name:

Date:

Address:

Notes:

	Raw material			Transport						
				Please provide as much information as possible - names of cities and ports are acceptable if distances are not known						
				Volume normally transported per order (tonne)	Truck journeys		Rail journeys		Ship journeys	
	Name	Origin			1	2	1	2	1	2
Example 1	Soybean meal	Argentina		300	500 km from farm to Buenos Aires port	80 km from HOME port to factory	0 km	0 km	Buenos Aires port to HOME port, Viet nam	0 km
Example 2	Soybean meal	USA		500	50 km from farm to Chicago	0 km	0 km	0 km	Chicago to HOME port	80 km from HOME port to factory
Example 3	Fishmeal	Viet Nam		50	140 km from port to factory	0 km	0 km	0 km	0 km	0 km
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
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17										
18										
19										
20										

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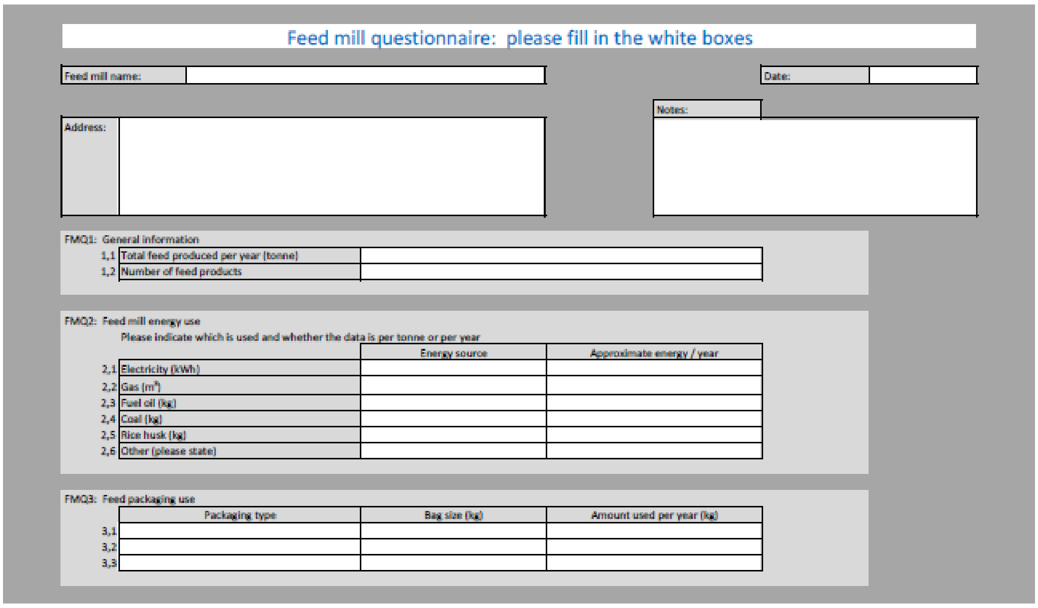
Feed mill questionnaire



Feed mill questionnaire: please fill in the white boxes

Feed mill name:

Date:

Address:

Notes:

FMQ1: General information

1,1	Total feed produced per year (tonne)	
1,2	Number of feed products	

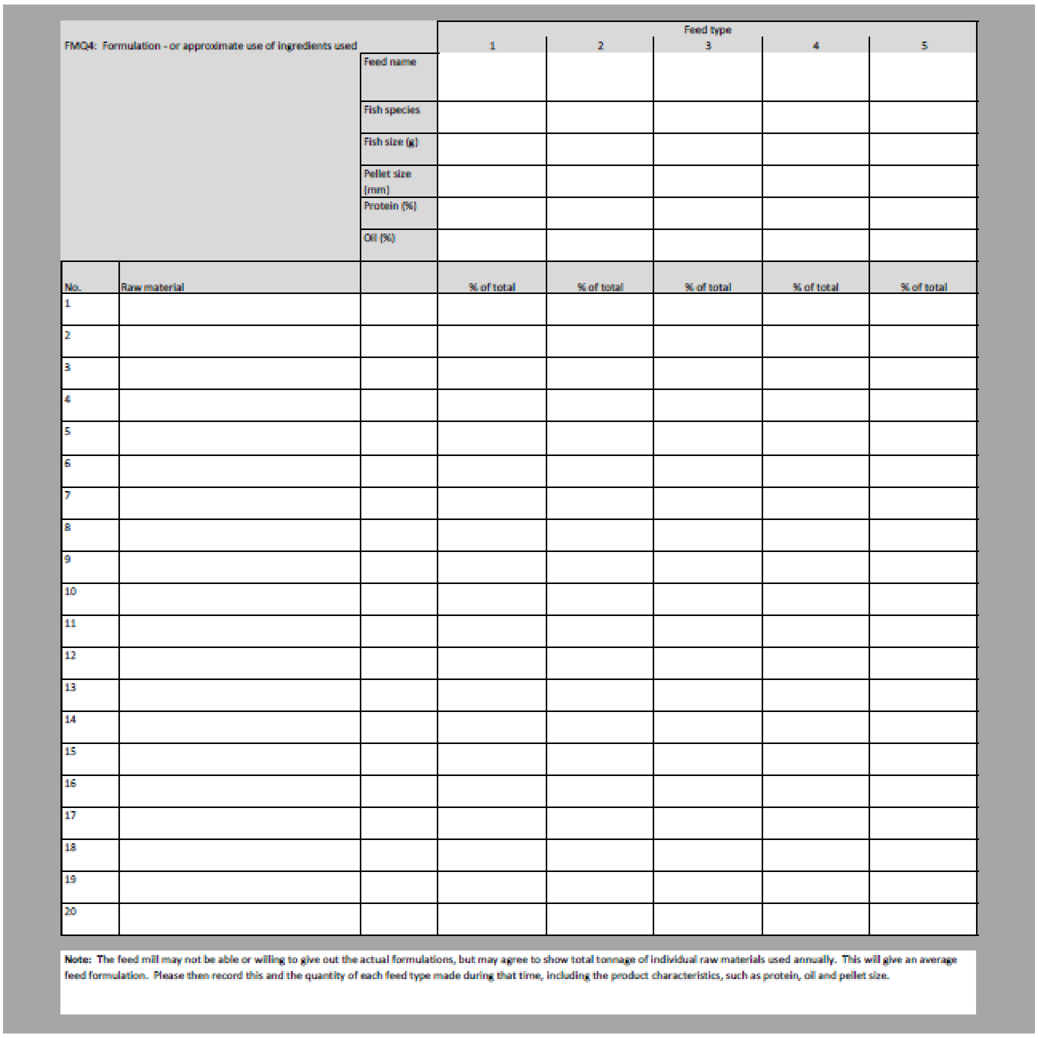
FMQ2: Feed mill energy use

Please indicate which is used and whether the data is per tonne or per year

		Energy source	Approximate energy / year
2,1	Electricity (kWh)		
2,2	Gas (m³)		
2,3	Fuel oil (kg)		
2,4	Coal (kg)		
2,5	Rice husk (kg)		
2,6	Other (please state)		

FMQ3: Feed packaging use

	Packaging type	Bag size (kg)	Amount used per year (kg)
3,1			
3,2			
3,3			



FMQ4: Formulation - or approximate use of ingredients used

			Feed type				
			1	2	3	4	5
		Feed name					
		Fish species					
		Fish size (g)					
		Pellet size (mm)					
		Protein (%)					
		Oil (%)					
No.	Raw material		% of total	% of total	% of total	% of total	% of total
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

Note: The feed mill may not be able or willing to give out the actual formulations, but may agree to show total tonnage of individual raw materials used annually. This will give an average feed formulation. Please then record this and the quantity of each feed type made during that time, including the product characteristics, such as protein, oil and pellet size.

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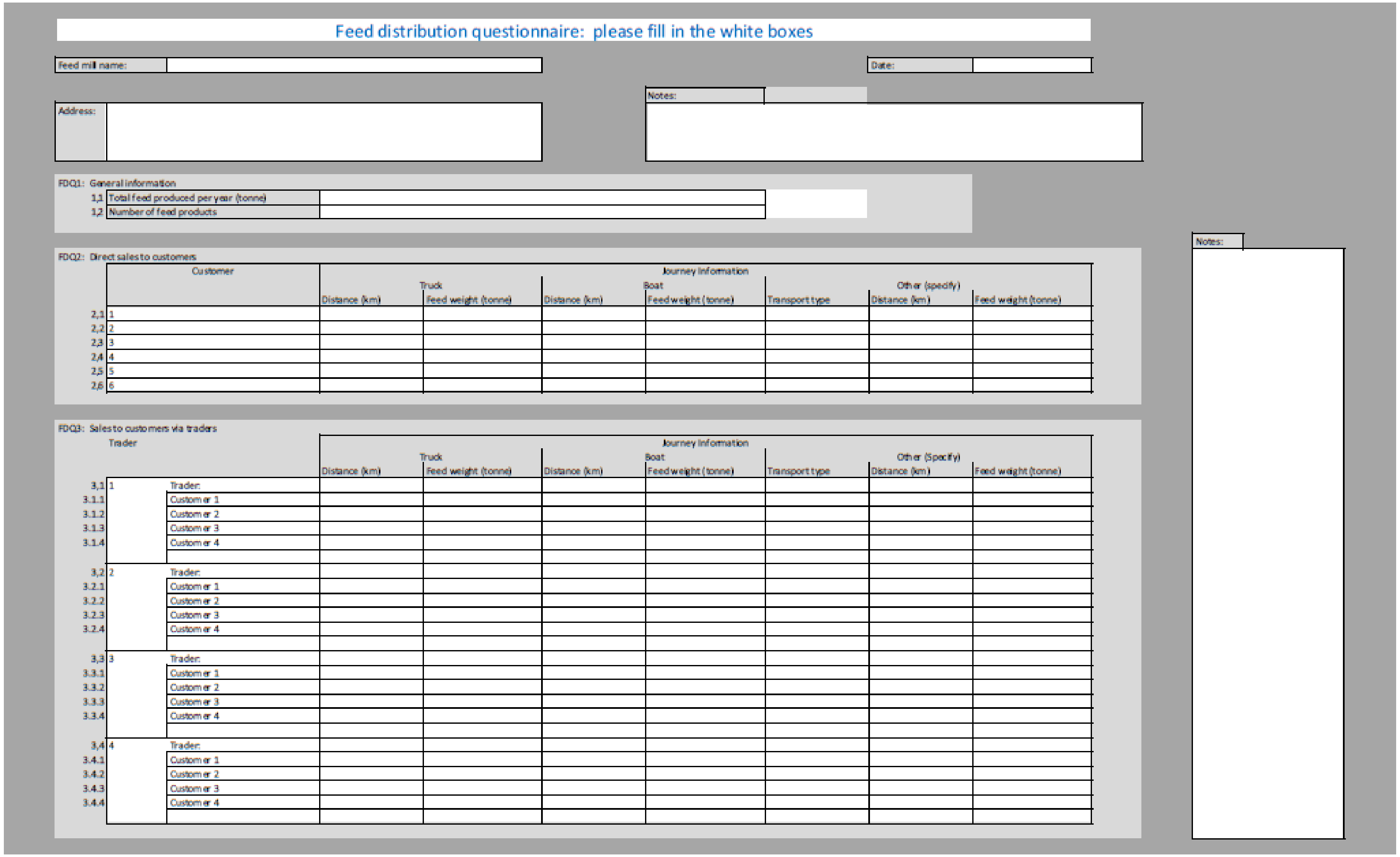
Feed distribution questionnaire



Feed distribution questionnaire: please fill in the white boxes

Feed mill name:

Date:

Address:

Notes:

FDQ1: General information

1,1	Total feed produced per year (tonne)	
1,2	Number of feed products	

FDQ2: Direct sales to customers

	Customer	Journey information						
		Truck		Boat			Other (specify)	
		Distance (km)	Feed weight (tonne)	Distance (km)	Feed weight (tonne)	Transport type	Distance (km)	Feed weight (tonne)
2,1	1							
2,2	2							
2,3	3							
2,4	4							
2,5	5							
2,6	6							

FDQ3: Sales to customers via traders

	Trader		Journey information						
			Truck		Boat			Other (Specify)	
			Distance (km)	Feed weight (tonne)	Distance (km)	Feed weight (tonne)	Transport type	Distance (km)	Feed weight (tonne)
3,1	1	Trader:							
3.1.1		Customer 1							
3.1.2		Customer 2							
3.1.3		Customer 3							
3.1.4		Customer 4							
3,2	2	Trader:							
3.2.1		Customer 1							
3.2.2		Customer 2							
3.2.3		Customer 3							
3.2.4		Customer 4							
3,3	3	Trader:							
3.3.1		Customer 1							
3.3.2		Customer 2							
3.3.3		Customer 3							
3.3.4		Customer 4							
3,4	4	Trader:							
3.4.1		Customer 1							
3.4.2		Customer 2							
3.4.3		Customer 3							
3.4.4		Customer 4							

Notes:

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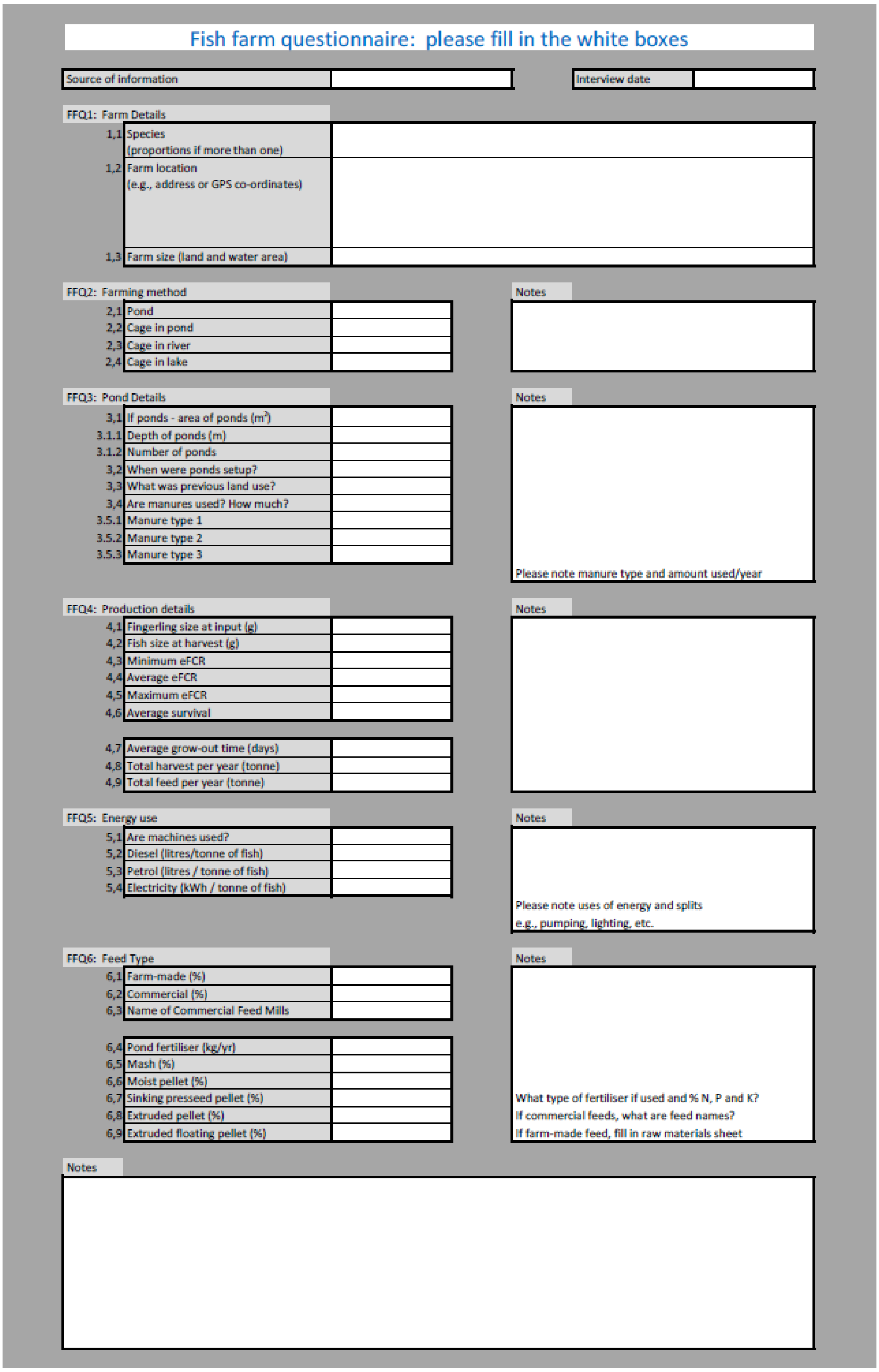
Fish - Farm questionnaire



Fish farm questionnaire: please fill in the white boxes

Source of information		Interview date	

FFQ1: Farm Details

1,1	Species (proportions if more than one)	
1,2	Farm location (e.g., address or GPS co-ordinates)	
1,3	Farm size (land and water area)	

FFQ2: Farming method

2,1	Pond	
2,2	Cage in pond	
2,3	Cage in river	
2,4	Cage in lake	

Notes

FFQ3: Pond Details

3,1	If ponds - area of ponds (m^2)	
3.1.1	Depth of ponds (m)	
3.1.2	Number of ponds	
3,2	When were ponds setup?	
3,3	What was previous land use?	
3,4	Are manures used? How much?	
3.5.1	Manure type 1	
3.5.2	Manure type 2	
3.5.3	Manure type 3	

Notes

Please note manure type and amount used/year

FFQ4: Production details

4,1	Fingerling size at input (g)	
4,2	Fish size at harvest (g)	
4,3	Minimum eFCR	
4,4	Average eFCR	
4,5	Maximum eFCR	
4,6	Average survival	
4,7	Average grow-out time (days)	
4,8	Total harvest per year (tonne)	
4,9	Total feed per year (tonne)	

Notes

FFQ5: Energy use

5,1	Are machines used?	
5,2	Diesel (litres/tonne of fish)	
5,3	Petrol (litres / tonne of fish)	
5,4	Electricity (kWh / tonne of fish)	

Notes

Please note uses of energy and splits
e.g., pumping, lighting, etc.

FFQ6: Feed Type

6,1	Farm-made (%)	
6,2	Commercial (%)	
6,3	Name of Commercial Feed Mills	
6,4	Pond fertiliser (kg/yr)	
6,5	Mash (%)	
6,6	Moist pellet (%)	
6,7	Sinking presseed pellet (%)	
6,8	Extruded pellet (%)	
6,9	Extruded floating pellet (%)	

Notes

What type of fertiliser if used and % N, P and K?
If commercial feeds, what are feed names?
If farm-made feed, fill in raw materials sheet

Notes

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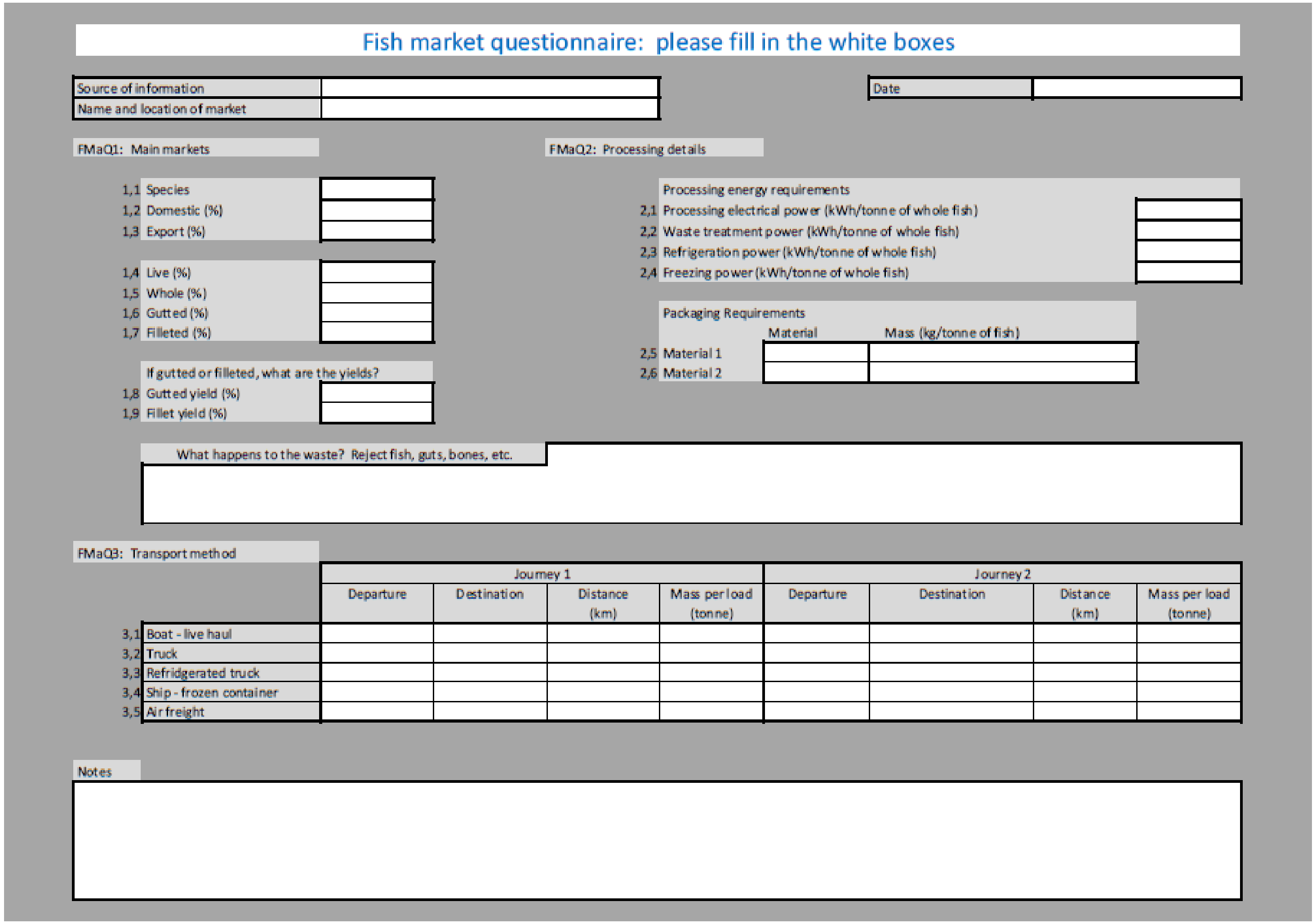
Fish - market questionnaire



Fish market questionnaire: please fill in the white boxes

Source of information	
Name and location of market	

Date	

FMaQ1: Main markets

1,1	Species	
1,2	Domestic (%)	
1,3	Export (%)	
1,4	Live (%)	
1,5	Whole (%)	
1,6	Gutted (%)	
1,7	Filleted (%)	

If gutted or filleted, what are the yields?

1,8	Gutted yield (%)	
1,9	Fillet yield (%)	

FMaQ2: Processing details

Processing energy requirements

2,1	Processing electrical power (kWh/tonne of whole fish)	
2,2	Waste treatment power (kWh/tonne of whole fish)	
2,3	Refrigeration power (kWh/tonne of whole fish)	
2,4	Freezing power (kWh/tonne of whole fish)	

Packaging Requirements

		Material	Mass (kg/tonne of fish)
2,5	Material 1		
2,6	Material 2		

What happens to the waste? Reject fish, guts, bones, etc.

FMaQ3: Transport method

		Journey 1				Journey 2			
		Departure	Destination	Distance (km)	Mass per load (tonne)	Departure	Destination	Distance (km)	Mass per load (tonne)
3,1	Boat - live haul								
3,2	Truck								
3,3	Refridgerated truck								
3,4	Ship - frozen container								
3,5	Air freight								

Notes

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