STATE OF MAINE

DEPARTMENT OF ENVIRONMENTAL PROTECTION

BOARD OF ENVIRONMENTAL PROTECTION

	IN THE MATTER OF
NORDIC AQUAFARMS, INC.	:APPLICATIONS FOR AIR EMISSION,
Belfast and Northport	:SITE LOCATION OF DEVELOPMENT,
Waldo County, Maine	:NATURAL RESOURCES PROTECTION
	:ACT, and MAIN POLLUTANT
	:DISCHARGE ELIMINATION SYSTEM
	:(MEPDES)/WASTE DISCHARGE
A-1146-71-A-N	:LICENSE
L-28319-26-A-N	:
L-28319-TG-B-N	:
L-28319-4E-C-N	:
L-28319-L6-D-N	:
L-28319-TW-E-N	:
W-009200-6F-A-N	:
ME0002771	

Assessment of the Nordic Aquafarms Permit to Satisfy Clean Water Act Requirements

TESTIMONY/EXHIBIT:	NVC/UPSTREAM 7
TESTIMONY OF:	George Aguiar
	James Merkel
DATE:	December 13, 2019

GEORGE AGUIAR

PROFILE

Over 34 years of software development experience concentrating on working with state-of-the-art technologies to solve hard problems. Roles span complete product development life cycle from conception and design to implementation thru deployment and sustaining phases. Fully deployable from project lead to direct heavy lifting with a history of being a key player on teams which successfully met their goals.

Specializing in Rapid Application Development, Object Oriented design and development using WordPress, CiviCRM, JavaScript, PHP, React, VisualStudio.NET building .NET Enterprise and web based Service Oriented Solutions with Silverlight, .NET RIA Services, ADO.NET Entities, ASP.NET, Web Services, ADO.NET, Windows Forms, WPF, WCF, Mobile Internet Toolkit and the Compact Framework in C# and VB.NET with agile approaches to using Microsoft Patterns and Practices.

EXPERIENCE

PRINCIPLE GEORGEAGUIAR.COM – 2011-PRESENT

Specialized version of CiviCrm, a CRM (Customer Relationship Management) system for nonprofits that focuses on Constituents, not Customers. Since 2011, have been providing CiviCrm on WordPress with custom options and training. Maintain websites for over 20 customers and nonprofits. Various long and short term engagements creating and maintaining websites and online web presence. Principle contractor for Promosis.Com: Design, build and maintain PHP websites and back end office tools for online marketing and incentive programs.

PRINCIPLE GLASSMENUS.COM, INC – 2009-2011

Designed and built backend website management tools using Silverlight 3.0, ADO.NET Entities, .NET RIA Services in C# using Visual Studio 8.0 and Blend 3.0 with service pack 1 employing TFS for source code control and project management. Designed and built Customer Relationship Management module which manages customer mailing list and integrates into Microsoft Word 2007 to compose and submit email content with integration into SmarterMail 5.5.

PRINCIPLE ENGINEER TJX COMPANIES – 2007-2009

Enhancements to TJX's customized Buyer Worksheet application; a customized order worksheet written in VB.NET 2005 using Windows Forms and Component One's C1FlexGrid and Excel C1XLBook components. Projects start with analyzing business requirements, writing full UML design documentation and working to construction completion thru quality assurance and deployment all in a SOX compliant and security aware environment. Provided team mentoring delivering classes on Unit Testing, Debugging .Net using Advanced Tools, and Using Team Foundation Version Control.

PRINCIPLE GLASSMENUS.COM – 2005-2007

Headed up development for startup company: OdoClub.com using Flex 2.0, Flash, AJAX, Windows WebForms for Presentation Layer, .NET 3.0, WCF Web Services, Windows Workflow for Business Layer and SQL Server 2005 with Strongly Typed DataSets for the Data Layer. Conceived, designed and implemented a templatized, vertical market website solution using ASP.NET 3.0, C#, WCF, Windows Workflow, Flex 2.0 and AJAX. Solution provides a vertical market website in a box that can easily and economically be used to quickly implement custom websites for a niche market.

SOFTWARE ARCHITECT BCGI – 2003-2005

Primary responsibility for overall architecture for Mobile-Guardian: BCGI's mobile phone access management solution. Duties include setting technical direction, recommending technologies and tools, designing, coding and testing. Analyzed business requirements and transformed marketing requirement documents into high level designs. Produced detailed designs including UML models and proof of concept prototypes. Provided team mentoring, validated code before check in and led technical aspect of interview process. Built and packaged software releases and provided installation and release documentation.

PRINCIPLE ENGINEER STRATUS COMPUTER – 2001-2003

Design and implementation of transition from heterogeneous Oracle 9i based high availability suite of tools to an n-tier .NET architecture based on Microsoft Best Practices and Architecture White Papers ASP.NET Web Forms, Business and Data Layers in C# passing Strongly Typed DataSets, Windows Management Instrumentation, Oracle SQL Mentoring of team members transitioning from ASP3.0/VB6.0 & VC++ 6.0 to .NET development environment including use of VS.NET 2003, Windows Server 2003, IIS 6.0, ASP.NET, ADO.NET and C#

VP PRODUCT ARCHITECTURE DASH.COM, INC. – 1999-2001

Responsible for next generation web site, data warehouse, and agent architecture built on top of IIS 5.0 and SQL Server 2000. Led initial development of IIS/ASP web site and browser based COM pluggin. Responsible for entire high volume web site and agent design, implementation and deployment on IIS web farm and SQL Server cluster. Brought initial concept from prototype to live in 7 months starting solo to build prototype for VC and then development lead. Led team of 17 developers on version 1 as VP of Development and 3 architects for subsequent releases as VP of Architecture.

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COUNTY OF Waldo

PERSONALLY APPEARED, George Aguiar, WHO, UNDERSTANDING THE MEANING OF AN OATH, SWORE THAT THE FORGOING TESTIMONY IS TRUE TO THE BEST OF HIS/HER KNOWLEDGE AND BELIEF, THIS 13th DAY OF DECEMBER 2019.

~~NOTERY~~ PUBLIC

Before me,

MY CO~~MMISSION~~ EXPIRES:

Miles D. Feieder
Attorney at Law

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

George Aguiar ______________ Date: 12/13/19

Printed Name: GEORGE AGUIAR
Title: SOFTWARE ENGINEER

Parties Assisting:

Name:	Address:	Signature:__________
Name:	Address:	Signature:__________

CTO ENGINEHOUSE MEDIA, INC – 1998-1999

Design and implementation of a first of a kind DNA-based Ad banner Management work flow product using Exchange/Outlook/IIS/ASP/SQL Server.

PRINCIPLE ENGINEER CENTRA SOFTWARE, INC – 1995-1998

Created Java/Swing client architecture and implemented framework. Designed and implemented Visual J++/Win32 client. Designed and implemented Java browser based client (applets).

SENIOR OPERATING SYSTEMS ENGINEER ALLIANT COMPUTER SYSTEM, INC – 1989-1995

Interactive performance enhancements to multi-processor OS. Device driver, computer resource and system accounting enhancements. Kernel base on UNIX – BSD 4.2.

SENIOR SOFTWARE ENGINEER NEC INFORMATION SYSTEMS INC – 1984-1989

Unix Engineering Workstation lead. PC UNIX (AT&T 5.1) work including internals, drivers, configuration, tuning and system management. Misc. projects: UUCP, Ethernet, NFS, RFS, graphics and X-Windows.

EDUCATION

NORTHEASTERN UNIVERSITY BOSTON, MA – BSEE 1983

SKILLS

Design and hands-on experience with PhpStorm, Microsoft Visual Studio.NET 2005/2008/2010, ASP.NET 1.1, 2.0 3.0, 3.5 & 4.0, Silverlight 3.0, .NET RIA Services, ADO.NET Entities, ADO.NET, Web Services, AJAX, Flex 2.0, Flash 8.0, ActionScript 3.0, WCF, Windows Workflow, Winforms, Mobile Controls, Microsoft Office, .NET Compact Framework, SQL Server 2000 & 2005, Oracle 9i, DHTML, JavaScript, XML, UML, ORM, ERD, Visio, Project, ASP, COM+ 1.5, MTS, MSMQ, C#, DNA, ASP, Visual C ++, Java, Visual Basic 6.0, C++, JSP, EJB, Swing.

James S. (Jim) Merkel: Resume
97 Patterson Hill Rd., Belfast, Maine 04915
(207) 323-1474, email: jimimerkel@gmail.com

Jim is sustainability professional who authored *Radical Simplicity*, a hands-on guide to quantifying and monitoring sustainability. In 1989 he transitioned from the military engineering sector to moving institutions and individuals toward sustainability by: founding organizations, assisting campuses and organizations in measuring ecological footprints, working as Dartmouth College's Sustainability Coordinator, creating city and regional transit and bike lanes and teaching sustainability at universities while experimenting in sustainable living.

Experience:

2014-Current **Filmmaker**, Independent, Belfast, Maine.

2005 – 2007 **Sustainability Coordinator, Dartmouth College**, Hanover, New Hampshire. Worked to integrate environmentally and socially sustainable practices into the College's operations, buildings, culture and strategic plan. Worked to reduce the carbon footprints of the campuses 110 buildings. His work helped Dartmouth College earn the highest grades on the Sustainability Report Card issued by the Sustainable Endowments Institute.

1994 – Present **Founder and director of The Global Living Project (GLP)**
Conducted five multi-week *GLP Summer Institutes* where educators and students lived on an equitable portion of the biosphere. Researched and developed the *100 Year Plan*, a societal approach to global sustainability.

1988 – 1994 **Environment & Community Volunteer Work**, San Luis Obispo, Ca.
Elected to Vice-Chair, Executive Committee Chair, and Conservation Committee Chair of the Santa Lucia Chapter of the Sierra Club. State and federal lobbyist. Drafted legislation. Presented positions on transportation, land-use planning, open-space, peace, water, wilderness, Native American and oil spill issues at over 100 public hearings. Co-founded the Big Mountain Support Group. Delivered humanitarian aid to Navajo families resisting forced government relocation.

1985 - 5/89 **TRW Electronic Products Inc.**, San Luis Obispo, California.
Business Development, Foreign Military Sales, Senior Engineer.

1984 - 1985 **ITT, Vandenberg AFB**, California.
Senior Electronic Engineer. Designed digital, R.F. and computer systems.

1977 - 1984 **Photocircuits**, Aquebogue, New York. Title: Electrical Engineer.

Teaching Experience:

2009-2014 **Unity College, Adjunct Professor**, Unity, Maine. Teaching *Environmental Issues and Insights*, which includes student documentaries.

2009 **Las Cañadas**, Veracruz Mexico. Instructor for weeklong ecological footprinting intensive.

2008 – 2009 **Community College of Vermont**, **Adjunct Professor,** Wilder, Vermont.

2008 – 2009 **Longwood University,** Farmville, Virginia. *Radical Simplicity* selected as reading for *First-year Experience 2008 & 2009*.

2005 **Antioch New England, Adjunct Professor,** Keene, New Hampshire.

2003 **University of British Columbia, Adjunct Professor,** Vancouver, B.C. Instructor for *The Science and Practice of Sustainability*.

Publications:

- *Radical Simplicity* selected for edited book, *Voluntary Simplicity – the poetic alternative to consumer culture*, Stead & Daughters Ltd, New Zealand, 2009.
- Chapter in *Less is more*, New Society Publishers, Canada, 2009.
- Author of *Radical Simplicity – small footprints on a finite earth* (in third printing), New Society Publishers, Canada, 2003. Spanish Translation *Simplicidad Radical*, Fundación Tierra, Spain, 2005

Awards:

2016 Arthur Morgan Award, Yellow Springs, OH.

2008 Living Hero Award, New Hampshire Life Magazine, Concord, NH.

2006 Graduation Speaker, The Putney School, Vermont.

2006 Graduation Speaker, Vermont Law School, Vermont.

2000 Sustainable Living Award, Environmental Youth Alliance, Vancouver, B.C.

1999 The Bill Deneen Award for Outstanding Environmental Leadership, Nipomo, Ca.

1994 Gaia Fellowship, Earthwatch, research low resource use and high life quality in Kerala, India. Researched light living in the Himalayas.

1992 Clean Air Award - American Lung Association, San Luis Obispo, Ca.

1991 Group of the Year Award for the Big Mountain Support Group - Economic Opportunities Commission, San Luis Obispo, Ca.

1991 Citizen of the Year Nomination - Economic Opportunities Commission, San Luis Obispo, Ca.

1990 Beyond War Award for work with the Earth Day Coalition, San Luis Obispo, Ca.

Academic Background:

- State University of New York at Stony Brook, B.S. in Electrical Engineering, May 1984.
- Suffolk County Community College, New York, A.A.S. in Electrical Technology, January 1981.

STATE OF MAINE

COUNTY OF Waldo

PERSONALLY APPEARED, James S. Merkel, WHO, UNDERSTANDING THE MEANING OF AN OATH, SWORE THAT THE FORGOING TESTIMONY IS TRUE TO THE BEST OF HIS/HER KNOWLEDGE AND BELIEF, THIS 13th DAY OF DECEMBER 2019.

M. D. F

~~NOTERY PUBLIC~~ Miles D. Frieden

MY ~~COMMISSION EXPIRES:~~ Attorney at Law

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

James S Merkel ______________________ Date: 12/13/2019

Printed Name: James S. Merkel

Title: Director: Global Living Project

Parties Assisting:

Name: Address: Signature:__________

Name: Address: Signature:__________

Authors:
James Merkel
George Augiar

Nordic Aquafarms' **Total** Carbon Footprint

Summary

The findings of this study include:

1. That the proposed facility is greenhouse gas (GHG) intensive, and that lower carbon solutions to feeding humanity are readily available. Our calculations have revealed that the applicant's annual GHG emissions represent approximately 5 to 6 percent of the 2030 total state GHG target.
2. If this facility were built and operated an unfair burden would be placed on existing businesses and residents to meet Maine's climate targets and the governor's executive orders.
3. The applicant should be required to amend their plan to:
   a.) demonstrate carbon neutrality utilizing wind and solar power.
   b.) find a Brownfield site that has stable soils to avoid releasing carbon stored in the forest and soil, and to maintain the sequestration of a mature 35 acres of forests and wetlands.
   c.) find a location with access to deep ocean currents, or utilize a completely closed system.

Our findings demonstrate that the construction (embodied CO2) and operations (CO2) of Nordic Aquaculture farms (collectively, "the Project") as proposed by the Applicant's Site Location and Development Permit Application (SLODA) to the Department of Environmental Protection (DEP) on 5/16/2019 (the "Application") adds significantly to statewide greenhouse gas emissions. Our calculation estimates have revealed that the applicant's GHG contribution of between 0.55 and 0.76 MMTCO2e represents 4.6 – 6.4 percent of the 2030 total state GHG target, and between 12.8 and 17.6 percent of the 2050 target. To approve these new large sources of carbon emissions, while making commitments to reduce GHG, violates the intent of PL 237, §576-A. This large-scale aquaculture facility proposed by Nordic Aquafarms (NAF) in Belfast, Maine would also

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make it difficult to "achieve carbon neutrality by 2045" as mandated by the Executive Order No. 10FY 19/20, signed by Governor Mills on September 23, 2019.[1]

By conducting three separate life-cycle assessments of Nordic's proposal, along with surveying similar assessments of other recirculating aquaculture systems (RAS), an estimate of both embedded and operational CO_2e (Life-cycle CO_2e = Embodied CO_2 + Operational CO_2) was established. The results support what the literature has determined: land-based aquaculture requires significant energy and feedstock, and produces large amounts of greenhouse gases (GHG).[2] [3]

Introduction

There is no shortage of warnings, reports and political statements concerning GHG emissions, and the irreversible consequences of climate change. The United Nations *Emissions Gap Report Summary* that was issued on November 26, 2019 states the situation clearly: "[The] findings are bleak. Countries collectively failed to stop the growth in global GHG emissions, meaning that deeper and faster cuts are now required."[4]
Business-as-usual has accelerated the crisis which

> "is more severe than anticipated, threatening natural ecosystems and the fate of humanity (IPCC 2019). Especially worrisome are potential irreversible climate tipping points and nature's reinforcing feedbacks (atmospheric, marine, and terrestrial) that could lead to a catastrophic "hothouse Earth," well beyond the control of humans (Steffen et al. 2018). These climate chain reactions could cause significant

1https://www.maine.gov/governor/mills/sites/maine.gov.governor.mills/files/inline-files/Executive%20Order%209-23-2019_0.pdf

[2]Monterey Aquarium Seafood Watch https://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/2015%20standard%20revision/public%20consultation%202/mba_seafoodwatch_criteria%20for%20greenhouse%20gas_msg_final.pdf?la=en

[3]Energy Use in Recirculating Aquaculture Systems https://www.researchgate.net/publication/323891940_Energy_use_in_Recirculating_Aquaculture_Systems_RAS_A_review

[4] UN Environment Programme, Emissions Gap Report 2019 https://www.unenvironment.org/resources/emissions-gap-report-2019

> disruptions to ecosystems, society, and economies, potentially making large areas of Earth uninhabitable." [5]

We are, as 11,000 scientists declared on November 5th in BioScience **in a climate emergency**.[6]

Maine

In 2003 Maine enacted PL 237. This law required that the DEP develop and submit a Climate Action Plan (CAP or Plan) for Maine, and mandates the reduction of GHG emissions. Specifically, under §576-A of PL 237 the State's goals for the reduction of emissions for 2020 are 10% below 1990 levels (21.65 MMTCO2e) by January 1, 2020, (19.46 MMTCO2e) which Maine is, according to the 2019 Maine Interagency Climate Adaptation work group (MICA) Update Report, on target to meet. However, §576-A mandates that "by January 2030 the State shall reduce gross annual greenhouse gas emissions to at least 45% below 1990 gross annual greenhouse gas emissions level" putting the 2030 target at 11.91 (MMTCO2e). Furthermore, the law mandates that "by January 1, 2050, the State shall reduce gross annual greenhouse gas emissions to at least 80% below the 1990 GHG emissions level," or to 4.3 (MMTCO2e). By comparison, the applicant's greenhouse gas contribution of between 0.55 and 0.76 MMTCO2e represents 4.6 – 6.4 percent of the 2030 total state GHG target, and between 12.8 and 17.6 percent of the 2045 target.

[5] Ripple, William J, Wolf, Christopher, Newsome Thomas M., Barnard, Phoebe, and Moomaw, William R. World Scientists' Warning of a Climate Emergency, *BioScience*, biz088, p. 3 https://doi.org/10.1093/biosci/biz088

[6] Ripple, William J, Wolf, Christopher, Newsome Thomas M., Barnard, Phoebe, and Moomaw, William R., World Scientists' Warning of a Climate Emergency, *BioScience*, biz088, https://doi.org/10.1093/biosci/biz088

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Belfast

As stated in the Belfast's Energy Committee's mission statement, "[t]he committee's objective is to recommend steps to the City Council and city residents that will reduce both greenhouse and air pollution emissions throughout the city." This facility will significantly increase local GHG emissions, while eliminating vital sequestration resources. The facility will also undermine the Belfast Climate Crisis committee's commitment to supporting and enhancing "Ecosystem-based Resilience." Their report states that "solutions [include] conserving and restoring smaller-scale natural ecosystems within the watershed (wetlands, river mouths, beaches, dunes, intertidal and subtidal habitats); designing containment areas; establishing appropriate vegetative cover along shorelines; and mandating low-impact development practices." The Nordic Aquaculture facility is not a "low-impact development practice."

Lifecycle Assessment (LCA) for CO2e

The intention of this research is to establish an estimate of the total carbon (TC) additions to Maine's annual CO2 emissions that can be expected, should the proposed Nordic Aquafarms facility be built in Belfast. Three separate Life-Cycle Assessment (LCA) tools/methodologies were used to establish a framework for accounting for many of the impacts typically ignored when only considering operational flows of resources. Figure 1. illustrates a simplified diagram for a rather complicated analysis. The desired scope for our purposes is to focus on CO2 equivalent emissions related to the entire facility from turning a complex, mature forested site into an industrial facility (concrete, steel, pumps and motors) and then summarizing the larger categories of operational inputs such as feeds, electricity, diesel fuel, and chemicals.

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Nordic Aquafarms' **Total** Carbon Footprint

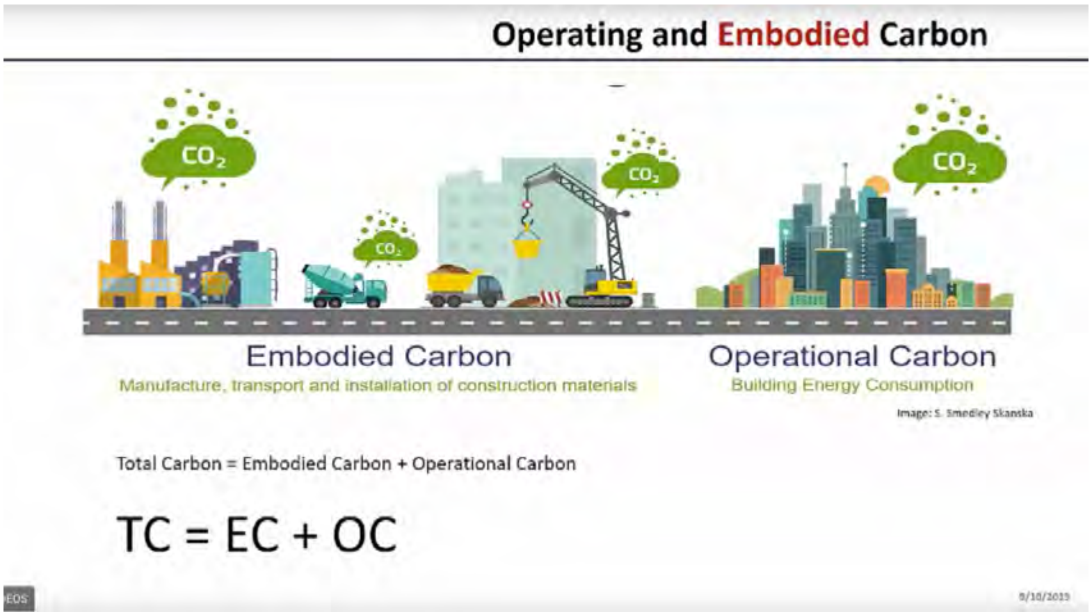

Figure 1

The analysis is an underestimate as many real impacts are difficult to quantify at the design stage, yet it provides a useful estimate for decision-making purposes. In the case of Nordic's proposal, extensive specialized buildings, fuel and chemical tanks, pipelines into the bay, comprise unique and carbon intensive structures, with a broad range of possible scenarios and risks should the project fail prematurely. LCA tools help plan for worst-case outcomes. Maine industries have historically left behind "wicked problems" such as mercury sediments covering miles of the Penobscot River[7], and dioxin pollution in several Maine Rivers.[8] This analysis does not include decommissioning at the end of the useful life of the facility, however, deconstruction at some point, will be carbon intensive.

[7] https://www.maine.gov/dep/spills/holtrachem/index.html

[8] https://www.nrcm.org/programs/waters/cleaning-up-the-androscoggin-river/maines-dioxin-problem/

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Few LCA studies have been conducted on land-based aquaculture. In 2015 Seafood Watch published research on energy use in a variety of aquaculture environments. Their analysis determined land-based recirculating aquaculture systems (LB-RAS) to be the most energy intensive of the studied methods.[9]

Figure 2: Energy use associated with aquaculture feeds (red bars) and farm level activities (blue bars) for a variety of species and production methods in units of megajoules/tonne of seafood, drawn from LCA studies and other information sources. Literature review carried out by Keegan McGrath. These data will be transformed into GHG Intensity per unit of edible protein (KgCO2 equivalent/Kg edible protein) when applied to this criterion.

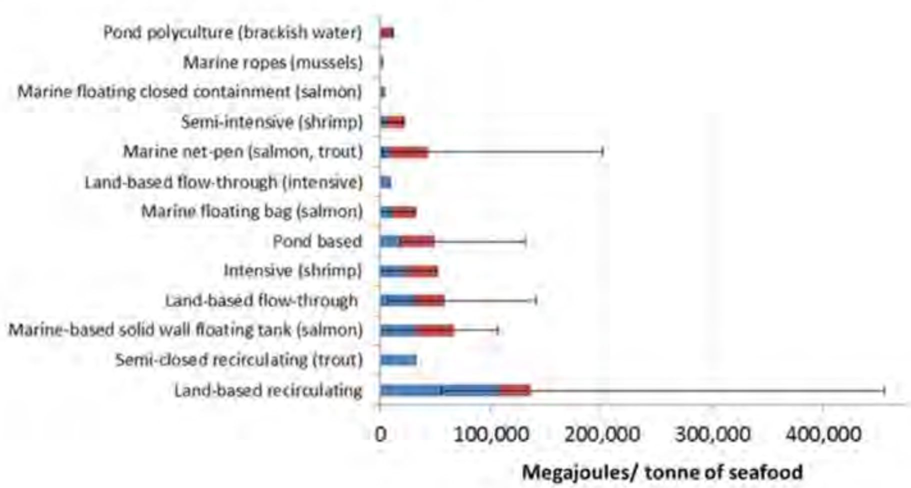

Figure 2: Energy and feed requirements of various aquaculture technologies.

In 2016, a study compared producing Atlantic salmon in open pens in seawater to a hypothetical land-based closed containment recirculating aquaculture system (LBCC-RAS) based upon the Conservation Fund's Freshwater Institute grow out trials of Atlantic salmon.[10] This is the study that the applicant sites to argue that salmon grown in a LBCC-

[9] Monterey Bay Aquarium Seafood Watch https://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/2015%20standard%20revision/public%20consultation%202/mba_seafoodwatch_criteria%20for%20greenhouse%20gas_msg_final.pdf?la=en

RAS system has a lower carbon footprint than shipping open net pen (ONP) salmon by airfreight to Seattle, Washington: 7.4kg CO2e/kg (RAS) vs. 15.2 kg CO2e/kg (airfreight from Norway to Seattle). Electricity to produce 1 tonne of salmon in RAS is cited as 5,460 kWh. However, shipping frozen salmon by container ship from Norway to the US was the lowest footprint option in this study at 3.75kg CO2e/kg.

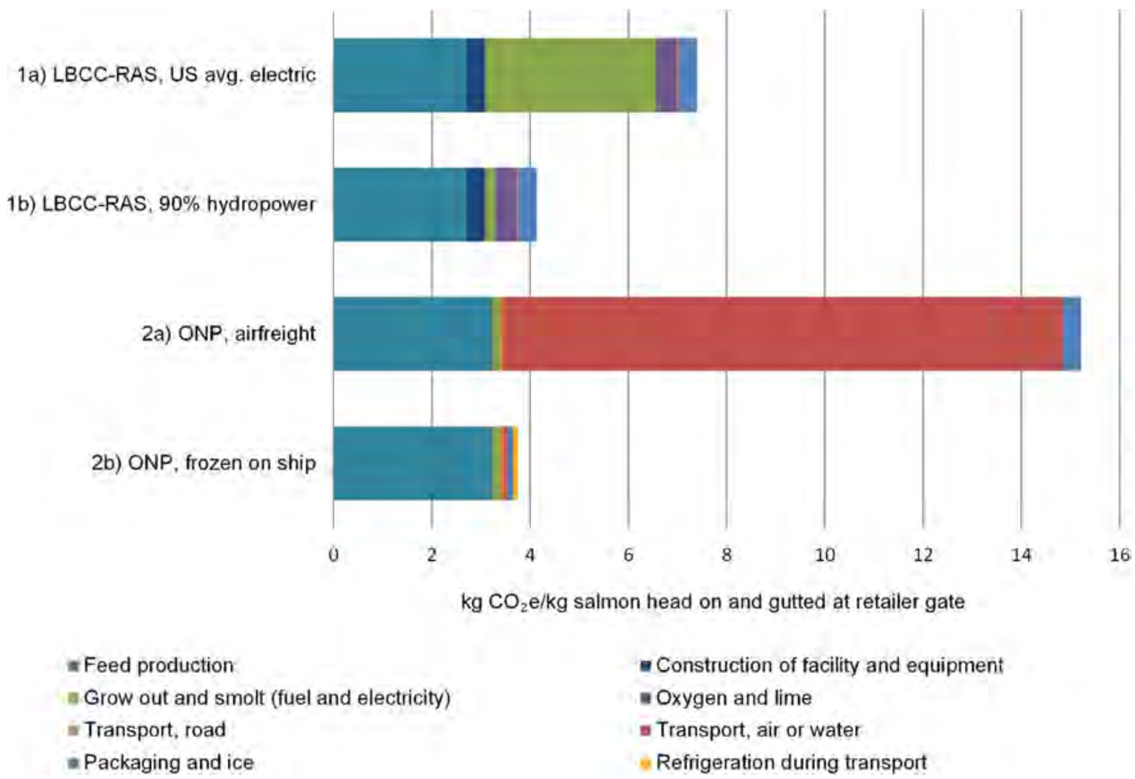

Figure 3: Fish Farm Carbon Footprint Comparisons from 2016 study

This 2016 study had a limited scope, and did not evaluate the carbon footprint of wild caught Maine seafood, or production of plant proteins which have lower carbon

[10] Yajie Liua, Trond W. Rostena, Kristian Henriksena, Erik Skontorp Hognesa,Steve Summerfeltb, Brian Vincib, Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (Salmo salar):Land-based closed containment system in freshwater and open net pen in seawater, in Aquacultural Engineering 71, (2016) 1-12. https://doi.org/10.1016/j.aquaeng.2016.01.001

footprints than the options this study evaluated. For example, wild caught Demersal fish (eg. Haddock) species have a life-cycle CO2e intensity of *2.4 kg CO2e/kg*. Small Pelagic fish (eg. Sardines) have a lifecycle CO2e of 0.2 kg CO2e/kg.[11] Vegetarian diets including legumes have CO2e in the range of 0.6 kg CO2e.[12]

A more recent LCA paper was published in 2019 which is the first analysis based upon actual data from growing out 29,000 salmon in northern China from 100 g smolts to 4 KG fish.[13] The results of this study were that to grow one tonne of live-weight salmon required 7,509 KWh of electricity and generated 16.7 tonnes of Co2e, 106 kg of SO2 e, 2.4 kg of P e and 108kg of N e (cradle to farm gate). The study cited electricity and feed as the larger components of the overall impact. This more recent study from an actual operation reported roughly double the tonnes of CO2e/tonne of fish compared to the 2016 FreshWater Institute Study (7.4 vs. 16.7).[14] The power per tonne of fish produced was 5,460 kWh in the 2016 study while the more recent China study was 7,509 kWh. Many factors can account for the differences such as power grid composition, fish food sources and makeup, different inventories and assumptions, however, the data are close enough to offer some confidence in their similar methodologies and findings.

[11]Parker, Robert W.R., Blanchard, Julia, Gardener, Caleb et al., Fuel use and greenhouse gas emissions of world fisheries in Nature Climate Change, VOL 8, APRIL 2018 p. 333–337 http://www.ecomarres.com/downloads/GlobalFuel.pdf

[12]Clune, S. J., Crossin, E., & Verghese, K., Systematic review of greenhouse gas emissions for different fresh food categories. *Journal of Cleaner Production*, *140*(Part 2), 766-783. http://www.research.lancs.ac.uk/portal/en/publications/systematic-review-of-greenhouse-gas-emissions-for-different-fresh-food-categories(153c618e-1b41-4cf4-b23e-7bc635cd2541).html

[13] Song, Xingqiang, Liu, Ying, Brandão, Miguel et al. Life cycle assessment of recirculating aquaculture systems: A case of Atlantic salmon farming in China in *Journal of Industrial Ecology*, Vol 23, Issue 5, Oct 2019, pp. 1077-1086 https://doi.org/10.1111/jiec.12845

[14] Yajie Liua, Trond W. Rostena, Kristian Henriksena, Erik Skontorp Hognesa,Steve Summerfeltb, Brian Vincib, Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (Salmo salar):Land-based closed containment system in freshwater and open net pen in seawater, in Aquacultural Engineering 71, (2016) 1-12. https://doi.org/10.1016/j.aquaeng.2016.01.001

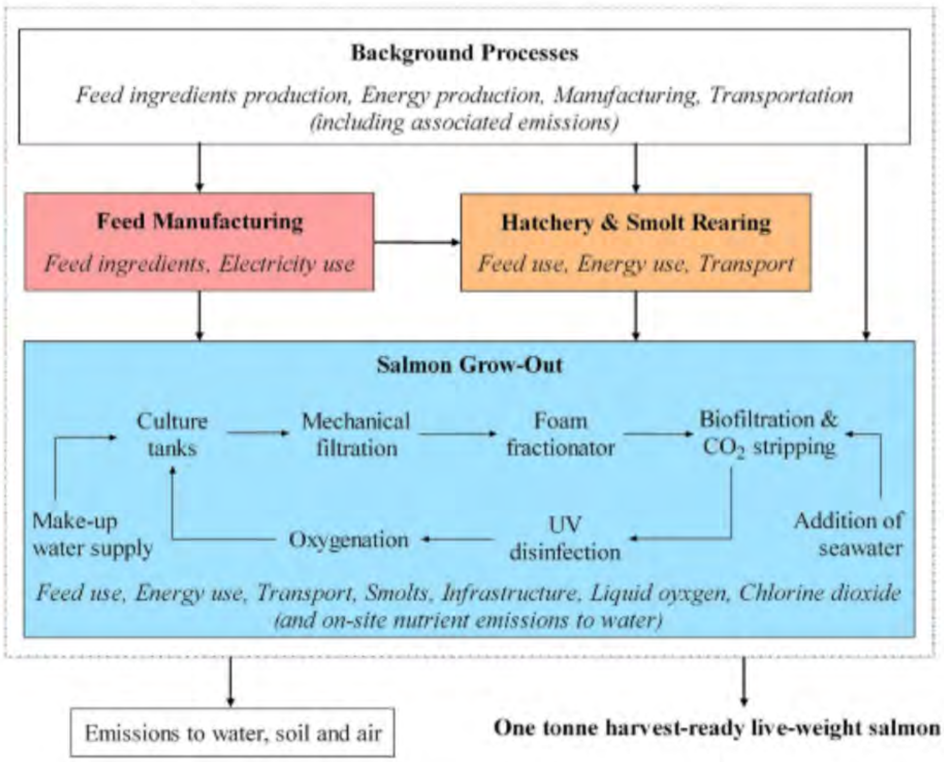

Figure 4: The boundary conditions for the 2019 China example

Figure 4 shows the system boundary and scope for the China example. Life-cycle inventories used SimaPro 8.3 software to capture many of the cradle-to-farm-gate inputs.

To obtain a first order of magnitude estimation for the applicant's proposed Belfast operation, we used the resulting LCA CO2e per metric tonne of fish data from the 2019 China study. At buildout, the proposed Belfast facility anticipates producing 33,000 t/year output. The CO2e from NAF is calculated (16.7 tC/t X 33,000 t/year) to emit 551,100 tCO2e per year from both embodied and operational components. For comparison, an average American car emits 4.6 t/yr, hence the NAF facility can be estimated to be equivalent to adding 119,800 cars to the roads.

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Generating specific LCA for the Belfast facility is difficult as the designs change regularly as would be expected for a complex project. We have attempted to be as up to date as possible while focusing on the larger footprint items. For example, earlier plans were for an approximate 18 football fields of roof top solar panels. The panels have been eliminated from the design and 8 diesel generators have been added. The generators use has changed from not just supplying back up power during ice storms, but to shave energy use on a daily basis to reduce the electricity billing rate. Additional changes include, the outflow pipelines being shortened from a mile and a half into Belfast Bay to ⅔'s of a mile. Earlier, 1.5 million gallons/yr. of Methanol was listed and recently was changed to 1 million gallons/yr. of a glycerin product MicroC 2000. Our calculations have kept pace with most reported changes, but are not exhaustive, rather an attempt to capture the larger construction details and design revisions.

In our second LCA analysis we used industry standard spreadsheet calculators looking at as much of the project as possible aiming to include the embodied carbon (EC) specific to this project. Traditionally, only steel and cement are calculated as they are commonly the biggest contributors to a construction projects' EC. Due to the nature of Land-Based RAS (LB-RAS) we attempted to include as many of the significant embodied carbon sources such as the Penobscot Bay pipeline (the design has changed from a trench to buried to above the seabed), the site preparation, backup electrical generation, etc.

Figure 3 is the table from the Conservation Fund's Freshwater Institute grow out trials of Atlantic salmon.[15] To this table, we have added the 2019 China analysis and the first analysis we performed using industry standard spreadsheet (SS1) calculations, an amended estimate of Nordic's annual CO2e emissions based upon amortizing the

[15] Conservation Fund's Freshwater Institute https://doi.org/10.1016/j.aquaeng.2016.01.001

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construction over a 15 year time frame. We've included the forest and soil carbon release, along with our own lifecycle assessment of the actual site plan released to the public.

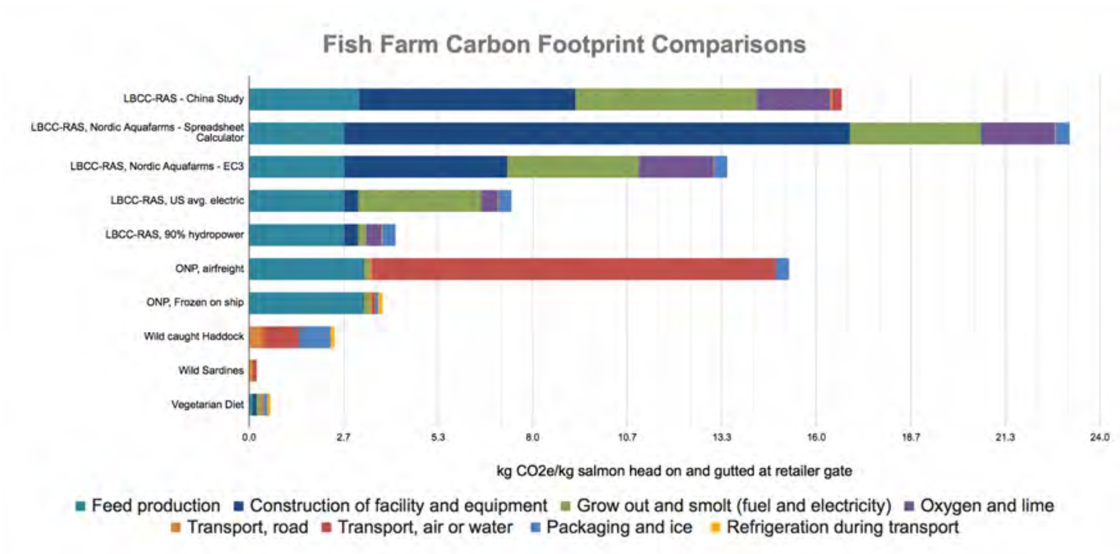

Figure 5: Fish Farm Carbon Footprint Comparisons including our 3 Analyses

In our 3rd analysis, we used the recently released Embodied Carbon for Construction Calculator (EC3). According to the Carbon Leadership Forum, this tool "is a free and easy to use tool that allows benchmarking, assessment and reductions in embodied carbon, focused on the upfront supply chain emissions of construction materials."[16]

This tool is currently in Beta 3 and the database of construction materials is limited to concrete and steel so we only looked at foundations and building envelopes. Unlike our more detailed and time-consuming calculator (SS1), which included tanks, motors, generators, etc, we were limited in Beta 3 to construction materials. By using several LCA tools, we were able to increase the confidence in our results.

[16] Carbon Leadership Forum http://carbonleadershipforum.org/projects/ec3/

Our results from the spreadsheet calculator, listed in Figure 5 as "BBCC-RAS Nordic Aquafarms - Spreadsheet Calculator" reported carbon intensity of approximately 23 kg CO2e/kg salmon. At buildout, the proposed Belfast facility, producing 33,000 t/year output would emit an estimated 759,000 tCO2e (23 tC/t X 33,000 t/year) from both embodied and operational components. This is equivalent to 165,000 cars to the roads.

Results & Discussion

Life-cycle Assessment – embodied carbon discussion

The life-cycle assessment results of the applicant's proposal support what the literature has determined: land-based aquaculture requires significant energy and feedstock, and produces large amounts of greenhouse gases (GHG).[17] Most significant inputs include: electricity for pumping water and operations; construction embodied energy for buildings, pipes, tanks, wells, pumps, motors, filters, generators; fish foods; forest and wetland elimination, and soil disturbances, are also important contributors.

The embodied carbon results are sensitive to the assumed lifespan of the infrastructure of the project. The China study used 15 years, and conducted a sensitivity analysis to include a 10 and 20-year option. For simplicity, our calculations used 15 years. The lifespan of a new technology is very difficult to predict. Should the facility close in half its expected life (due to falling salmon prices, disease outbreaks, technical issues, or saltwater intrusion on wells) the embodied carbon footprint would double.

It is important to point out that there are many impacts that can and can't be measured using LCA, however, this paper focused upon CO2e emissions from construction and

[17] Monterey Bay Aquarium Seafood Watch https://www.seafoodwatch.org/-/m/sfw/pdf/standard%20revision%20reference/2015%20standard%20revision/public%20consultation%202/mba_seafoodwatch_criteria%20for%20greenhouse%20gas_msg_final.pdf?la=en

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operation. RAS facilities of the scale proposed are lacking a history of performance and operating data, which would make for a more accurate LCA. However, the China LCA, which has some actual operational data and a solid methodology, along with a team of researchers, is a useful benchmark.

LCA methods can assist in identifying some of the potential unanticipated impacts of an applicant's project. In this case, a large-scale monoculture discharging into shallow and recovering marine environments create risks that might require regular maintenance, and replacements of filters, pumps and controllers and possibly additional heating and cooling of discharge and intake water that could increase or decrease the estimates in our analysis. Practical difficulties were not included in our analysis, such as construction disputes or design flaws that could drive up embodied and operational emissions. The real-world complexity of both ecosystems and human systems, dictate that these estimates are likely conservative.

It is worth noting that only one of our analysis methods attempted to estimate the total carbon of the eight 2MW generators and diesel engines, the smolt tanks, pumps, and other equipment and machinery, the roadways, parking lots and walkways and the pipeline into the bay. In this analysis, we made the best estimates working from the drawings supplied to Belfast City Planning Office.

Life-cycle Assessment – operational carbon discussion

With electricity and feed among the primary operational footprint drivers of RAS carbon footprint, several limitations in our analysis are noted below:

1) To complete a more accurate LCA would require specific fish feed composition, including the breakdown of amounts of small fish in the feed, chicken and pig slaughterhouse wastes, grains and pulses etc. Feed components derived from fish are regularly shipped from South America. The applicant has not yet decided

exactly what they will feed their fish. It is also imperative to note that current fish meal is impacting some of the poorest people on the planet, destroying wild food sources for wild fish, and intensifying the impacts of the climate crisis.[18] Many of the small fish used as feed are eaten in other parts of the world and threatened by largescale harvests as feedstocks.

2) The applicant has not been forthcoming with data such as design estimates of annual electricity consumption, so our results have had to make estimates based upon generator sizing checked against the data from other LCA assessments.
3) Maine's electricity grid power source mix might seem favorable given the considerable potentially "renewable" sources utilized. Some sources for CO2 emissions data make assumptions that biomass and hydroelectric are "carbon neutral" and "renewable," however, these terms are inaccurate in accounting for the life-cycle impacts of these energy sources.[19]

Maine's 2017 power-grid used biomass (26%) and hydro-electric (30%). Wood biomass has a higher CO2 per BTU than coal.[20] Hydroelectric dams, while considered to be carbon neutral, are proving to release large amounts of Ch4 and CO2.[21,22]

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[18] Green, Matthew "Plundering Africa: Voracious Fishmeal Factories Intensify the Pressure of Climate Change",*Reuters*October 13, 2018 https://www.reuters.com/investigates/special-report/ocean-shock-sardinella/

[19] Harvey, Chelsea, Heikkinen, Niina, Congress Says "Biomass Is Carbon-Neutral, but Scientists Disagree: Using wood as fuel source could actually increase CO2 emissions", in *Scientific America*E&E News, March 23, 2018 https://www.scientificamerican.com/article/congress-says-biomass-is-carbon-neutral-but-scientists-disagree/

[20] *Carbon Emissions from Burning Biomass for Energy* in Partnerships for Policy Integrity https://www.pfpi.net/wp-content/uploads/2011/04/PFPI-biomass-carbon-accounting-overview_April.pdf

[21] Deemer, Bridget R. Harrison, John A. Li, Siyue et al. *Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis*, in BioScience, Volume 66, Issue 11, 1 November 2016, Pages 949–964, https://doi.org/10.1093/biosci/biw117

[22] Graham-Rowe, Duncan**,** *Hydroelectric Power's Dirty Secret Revealed in New Scientist,* 24 February 2005 https://www.newscientist.com/article/dn7046-hydroelectric-powers-dirty-secret-revealed/#ixzz67klj5iSG

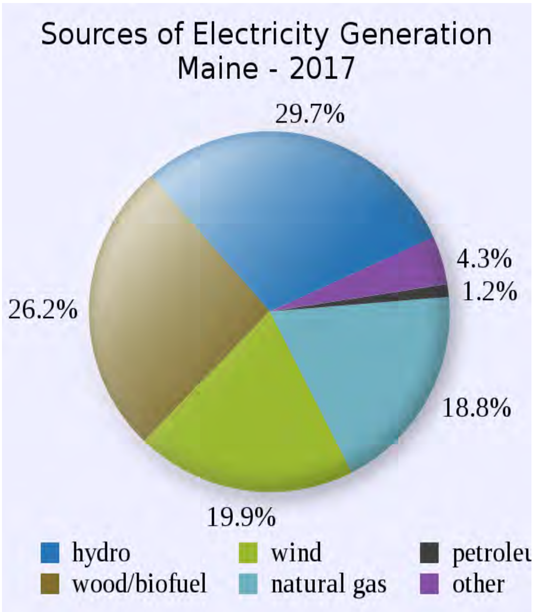

Figure 6

The combustion of wood results in 213 lb CO2/mmbtu (bone dry) while Bituminous coal comes in slightly lower at 205.3 lb CO2/mmbtu.[23] Forests are very effective in sequestering and storing carbon. It is argued that "trees grow back," true, however the lag time for the young forest to sequester carbon at rates that mature forests can is decades long, while the release of carbon from biomass generators is instantaneous. It is the old "slow in, fast out problem."[24] Biomass is only renewable if cut rates and forest practices don't diminish the ecosystem services while harvesting the biomass, (easy to state, difficult to achieve). And while the cutting is taking place, the habitat is under stress, soils and biodiversity are disturbed or eliminated, and forest resilience and long-term health are diminished. All of which can result in additional C02 emissions.

[23] Carbon emissions from burning biomass for energy https://www.pfpi.net/wp-content/uploads/2011/04/PFPI-biomass-carbon-accounting-overview_April.pdf

[24] Moomaw, William R., Masino, Susan A., Faison, Edward K., *Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good* in Frontiers in Forests and Global Change, June 2019, Vol 2, pp 1-27. https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full

Hydro-electric dams result in methane and CO2 release, and the elimination of large tracks of forest lands that sequester and store carbon above and below the surface, and provide critical habitat for biodiversity. A 2016 paper, found that GHG emissions from reservoir water surfaces account for 0.8 (0.5–1.2) Pg CO_2 equivalents per year, with the majority of this forcing due to CH_4[25]. It can be viewed as ironic that the very dams that have prevented untold millions of salmon from reproducing are now used to claim low carbon footprints for contained salmon that never see the light of day. The point being raised is that technologies such as large-scale hydroelectric plants solve one problem (cheap electricity) while creating other problems (eg. Ch4 and CO2 release, habitat destruction, loss of fishery).

The applicant plans to install 9 diesel generators, using 900,000 gallons of fuel resulting in 9142 metric tons of CO2e annually. This is equal to adding an additional 1,988 cars to Belfast's roadways. In addition to CO2 emissions, the air quality impacts and noise need to be considered, especially during periods of poor air quality and climate inversions.

Forest, wetlands, and soil removal

The facility requires the elimination of 34 acres of secondary growth mature pine and hardwood trees, and the removal of between 15 and 48 feet of soil totaling an estimated 215,000 cubic yards. It also requires the complete elimination of ten wetlands, nine of which are wetlands of special significance (WOSS). three significant streams will also be eliminated.[26] It is estimated that the forest, and the 17 wetlands of varying sizes, currently

[25] Deemer, Bridget R. Harrison, John A. Li, Siyue et al. *Greenhouse Gas Emissions from Reservoir Water Surfaces: A New Global Synthesis*, in BioScience, Volume 66, Issue 11, 1 November 2016, Pages 949–964, https://doi.org/10.1093/biosci/biw117

[26] While the GHG impact of this is not included in these findings, it is recommended that they be calculated and understood. As stated in the application: https://www.maine.gov/dep/ftp/projects/nordic/applications/NRPA/Attachment%2009%20-%20Site%20Condition/NRPA_A9_SiteConditions_text.pdf

store approximately 13,465 metric tons of carbon above and below ground. Left intact, this forest's current sequestration rate is approximately 42.9 metric tons of carbon each year. Current research is showing that trees increase their carbon sequestration significantly as they age[27,28]. In addition, forests and wetlands have a high value providing multiple ecosystem services, and William R Moomaw's recent work establishes that proforestation, meaning enhancing older forests, is actually the most viable way to achieve CO2 Targets[29].

A large quantity of carbon is stored in forest soils, and is released upon deforestation and disturbance.[30] According to the application "[e]xcavation required to construct the foundations and lower levels of the grow modules will be approximately 15 to 20 feet below the existing grades. The water treatment building includes 2 stories below grade, requiring a cut up to approximately 48 feet below the existing grades to accommodate construction of the lower level and a seawater intake pipeline."[31] Because the soils will have to be removed due to the fact that, "the native silt and clay soils that will be

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"There will be a total of 1,325 linear feet (LF) of impacts to streams within the project area (**Table 9-5**). Streams S3, S5, S6, and S9 will be indirectly impacted by the project. Impacts to stream S9 will be limited to a permanent crossing located between wetlands W8 and W9, along with a temporary crossing during the installation of the force main sewer line. The permanent crossing will be constructed in such a manner to not impair flow during storm events. The upper reaches of streams S3, S5, and S6 will be filled as a result of this project. These filled streams will result in the loss of 1,180 LF of stream bed. Impacts to these streams will typically result in the loss of Groundwater Recharge/Discharge, Floodflow Alteration, and Wildlife Habitats in these locations."

[27] Anderson, Mark G., *Wild Carbon: A Synthesis of Recent Findings* in Wild Works, Volume 1 Northeast Wilderness Trust http://www.newildernesstrust.org/wp-content/uploads/2019/08/WildWorks_V1_WildCarbon-2.pdf

[28] Moomaw, William R., Masino, Susan A., Faison, Edward K., *Intact Forests in the United States: Proforestation Mitigates Climate Change and Serves the Greatest Good* in Frontiers in Forests and Global Change, June 2019, Vol 2, pp 1-27. https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full

[29] Moomaw, William R., Masino, Susan A. et al. *Intact Forests in the United States*, in Frontiers https://www.frontiersin.org/articles/10.3389/ffgc.2019.00027/full

[30] Dartmouth College. "Clear-cutting destabilizes carbon in forest soils, study finds." ScienceDaily, 15 April 2016. www.sciencedaily.com/releases/2016/04/160415125925.htm

[31] Ransom Project 171.05027.005 Executive Summary Page 1 of 2 Belfast Geotechnical Report\02-03 Report\February 2019 Report\Text Rev.2_final February 27, 2019

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excavated are not suitable for reuse as structural fill at the site"[32] a large portion of all the carbon stored in the soils will be emitted into the atmosphere.

Recommendations:

1. **The applicant be required to demonstrate carbon neutrality and not place increased burden for CO2 reductions on Maine's population. Solar and wind generation have become economically viable for the applicant to utilize.**
2. **The applicant should not be permitted to clear a mature forest that currently sequesters carbon or remove soils and wetlands that are currently storing carbon. Rather, they should be required to find a Brownfield site that has stable soils.**
3. **Our LCA studies show that other lower carbon footprint foods are available in Maine.**
4. **The applicant should be required to find a location with access to deep ocean currents, or utilize a completely closed system.**

Conclusion

Our study concludes that proposed facility is CO2e intensive and that lower carbon solutions to feeding humanity are readily available. Our calculations have revealed that the applicant's GHG emissions are between 0.55 and 0.76 MMTCO2e. This represents 4.6 – 6.4 percent of the 2030 total state GHG target, and between 12.8 and 17.6 percent of the 2045 target. To approve these new large sources of carbon emissions, while making commitments to reduce GHG, violates the intent of PL 237, §576-A.

[32] Nordic Aquaculture SLODA Application https://www.maine.gov/dep/ftp/projects/nordic/applications/SLODA/Section%2011%20-%20Soils/Appendix%2011-B.%20Geotechnical%20Engineering%20Report.pdf

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A final consideration must include the unfair burden of further reductions that existing businesses and residents will have to make to meet Maine's targets and the governor's executive orders if this facility is approved. As stated in the Climate Action Plan for Maine, (CAP) getting to Carbon Neutral by 2045 will not occur under "business-as-usual" scenarios, rather it will require that any future large developments demonstrate carbon neutrality, and preferably be carbon positive.[33] There is a need for the DEP, and the State of Maine, to avoid placing additional burdens on existing enterprises, and to require that new businesses use strategies to achieve carbon neutrality with their proposals.

This facility would use Maine's "commons" including the clean aquatic sea water to dilute effluent, clean ground water, and clean air to receive diesel emissions and capacity on the power grid. The public suffers the loss, while the industry makes profits. Extractive industries should not put the burden of proof on its citizens. With several other RAS facilities proposing to come to Maine (Bucksport, Jonesport, Millinocket…) the CO2 implications are significant.

Maine has made progress towards meeting its climate goals, however, the next set of reductions will be more difficult, as Maine's shifting to fracked natural gas, biomass and hydroelectric each have serious impacts. More solar and wind energy will be helpful. As society grapples with sustainability and climate change, the challenge of new technologies is to solve past problems without creating new problems. The DEP should therefore not approve the NAF project as submitted, for the long list of problems and risks it creates as an untested, new technology. The DEP could require NAF to submit a carbon neutral design utilizing solar and wind power on a brownfield site that connects to

[33] Maine Climate Action Plan,
https://www.maine.gov/dep/sustainability/climate/MaineClimateActionPlan2004.pdf

deep ocean currents, or is a closed system. Finally, much better options are available for feeding humanity through local organic vegetable protein, and lower trophic level wild local fish eaten sparingly, a movement known as "Slow Fish"[34] while wild fisheries are restored.

34 https://www.slowfood.com/slowfish/pagine/eng/pagina--id_pg=44.lasso.html

EXHIBIT A7

Executive Order

OFFICE OF
THE GOVERNOR

NO. 10 FY 19/20
DATE September 23, 2019

AN ORDER TO STRENGTHEN MAINE'S ECONOMY AND ACHIEVE CARBON NEUTRALITY BY 2045

WHEREAS, climate change is having negative impacts on Maine and if not addressed will have devastating effects on the state;

WHEREAS, the Gulf of Maine is the second fastest-warming portion of the world's oceans, impacting the state's marine life, environment and commercial fishing;

WHEREAS, the growing seasons in Maine have become unpredictable with erratic frosts, hotter and drier summers, and more severe precipitation events that disrupt agriculture operations;

WHEREAS, the Maine economy is heavily dependent on natural resources including forestry, fisheries, maple sugaring, agriculture and tourism associated with outdoor recreation;

WHEREAS, Maine has abundant forests and working lands that are central to the natural resource-based economy, soil health and quality of life, and their sustainable management can meaningfully improve carbon sequestration;

WHEREAS, clean energy development, energy efficiency, innovation and carbon sequestration through the state's natural resources represent significant opportunities for Maine's economy;

WHEREAS, Maine's universities can produce leading research on climate change, offshore wind, wood-based composites, and biofuels, and Maine's community colleges can provide effective job training for businesses and employees engaged in a growing clean energy economy;

NOW THEREFORE, I, Janet T. Mills, Governor of the State of Maine, pursuant to *Me. Const. Art V, Pt 1, Secs, 1 and 12,* do hereby Order as follows:

I. PREFACE

Maine recently established mandates to reduce greenhouse gas emissions 45 percent below 1990 levels by 2030 and 80 percent by 2050; and a renewable energy mandate of 80 percent renewable energy by 2030 and a goal of 100 percent by 2050. Maine also recently established the Maine Climate Council responsible for Maine's Climate Action Plan to achieve emission reductions and clean energy targets as well as adaptation strategies by December 1, 2020 and to update that plan every four years. Finally, Maine recently joined the United State Climate Alliance, a bipartisan coalition of 25 states committed to addressing climate change.

II. POLICY GOAL

To further the work that is recently underway, Maine shall strive to achieve a carbon neutral economy no later than 2045. The Maine Climate Council shall provide recommendations required to meet these goals in its first report to be issued no later than December 1, 2020, and in every report thereafter.

III. COORDINATING EFFORTS AND INITIATIVES

All policies and programs undertaken to achieve carbon neutrality shall be implemented in a manner that aims to grow the state's economy, protect natural resources, and achieve positive impacts for the people of Maine. The Governor's Office of Policy Innovation and the Future shall coordinate the efforts of the Governor's Energy Office, the Departments of Environmental Protection, Economic and Community Development, Labor, and Agriculture, Conservation and Forestry. The Office shall coordinate the development of policies to advance the sequestration of carbon emissions and grow the clean energy economy in Maine.

IV. REPORTING

The Department of Environmental Protection shall develop a framework for accounting and tracking progress on greenhouse gas reduction, and report on such progress every other year.

V. EFFECTIVE DATE

The effective date of this Order is September 23, 2019.

Janet T. Mills
Governor

Monterey Bay Aquarium
Seafood Watch

Seafood Watch® DRAFT Greenhouse Gas Emissions Criteria for Fisheries and Aquaculture

Multi Stakeholder Group Draft

Contents

Introduction

The Monterey Bay Aquarium is requesting and providing an opportunity to offer feedback on the Seafood Watch Greenhouse Gas (GHG) Emissions Assessment Criteria for Fisheries and Aquaculture during our current revision process. Before beginning this review, please familiarize yourself with all the documents available on our Standard review website.

Providing feedback, comments and suggestion

This PDF document contains the second drafts of the GHG Emissions Criterion for Fisheries and the GHG Emissions Criterion for Aquaculture. A summary of the changes made to the first draft as a result of feedback during the first consultation process is provided at the end of the document, and individual changes are highlighted in the public comment guidance throughout. In their current form, these criteria are companions to the Fisheries and Aquaculture Assessment Criteria and are **unscored** due to data limitations. Seafood Watch will use these criteria to stimulate data collection and may score them in the future. "Guidance for public comment" sections have been inserted and highlighted, and various general and specific questions have been asked throughout. Seafood Watch welcomes feedback and particularly suggestions for improvement on any aspect of the Energy (GHG Emissions) Criteria. Please provide feedback, supported by references wherever possible in any sections of the criteria of relevance to your expertise. Please use the separate GHG Criteria Comment Form, which contains the excerpted "Guidance for public comment" sections from the PDF, to provide your comments.

These criteria were developed in close consultation with Dr. Peter Tyedmers of Dalhousie University, and Seafood Watch is indebted to Dr. Tyedmers for his time and dedication to this effort.

Seafood Watch DRAFT Energy Criteria for Fisheries and Aquaculture

MSG guidance - This section contains the draft guiding principle for the Energy (GHG Emissions) Criteria, which has been edited since the first public consultation to acknowledge the contribution of GHGs to the acceleration of climate change and to acknowledge that GHG emissions from food production are a significant fraction of anthropogenic GHG emissions.

Guiding Principle

The accumulation of greenhouse gases in the earth's atmosphere and water drives ocean acidification, contributes to sea level rise, affects air and sea temperatures, and accelerates climate change. GHG emissions from food production are a significant fraction of anthropogenic GHG emissions[1,2]. Sustainable fisheries and aquaculture operations will have low greenhouse gas emissions compared to land-based protein production methods.

MSG guidance - This section contains an overview of GHGs associated with seafood (and other protein) production methods, the draft rationale and summary for the Energy (GHG Emissions) Criteria for fisheries and aquaculture. This section has been edited since the first public consultation to include the overview of GHG emissions from fisheries and aquaculture. It also contains information about the GHG emissions included in our approach comparing up to the farm gate/dock emissions from seafood to land-based proteins (poultry and beef). In addition, we've clarified that we will be using the median values for comparative protein GHG intensities. Seafood Watch would like to be able to supplement or find replacement values for these comparative GHG intensities which factor soil CO_2 emissions into total GHG emissions, and welcome suggestions for comprehensive, robust values calculated with a uniform methodology for at least poultry and beef.

Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production

The range of GHGs associated with food production are diverse, and not always well described or quantified in life cycle analysis studies about these emissions (Henriksson *et al.* 2012). Here we describe the main GHGs associated with food production up to the farm gate or dock.

The primary GHG emissions associated with wild capture fisheries are from CO_2 emitted via direct fossil fuel combustion. Fossil fuels are used for propulsion, deployment and retrieval of fishing gears, powering cooling systems and other activities (Parker 2015). Other potentially significant GHG emissions from fisheries are associated with refrigerant use (Ziegler *et al.* 2011) and while not GHGs, short-lived, climate-forcing agents, namely black carbon or soot (incompletely oxidized organic carbon), are produced from fuel combustion (McKuin & Campbell In Review).

The GHGs associated with aquaculture production are more varied than those associated with wild capture fisheries and depend on the production method, species farmed and energy input regime (Pelletier et al 2011). These GHGs can include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). Aquaculture CO_2 emissions are associated with farm level energy use and feed production. Feed production CO_2 emissions include both energy use emissions as well as non-energy emissions from soils. These soil CO_2 emissions are associated with land conversion and land use and are not always well described or quantified (Nijdam *et al.* 2012). N_2O emissions are associated with fertilizers used on feed crops (Pelletier & Tyedmers 2010) and from surface waters induced by microbial nitrification and denitrification (Hu *et al*. 2012). CH_4 emissions are associated with feed production and organic material degradation (Nijdam *et al*. 2012). For fed systems, feed production can represent a significant proportion of emissions (Pelletier *et al*. 2011).

[1] An overview of GHG emissions levels associated with food production (including fisheries and aquaculture) are available from the FAO (FAO 2011)

[2] An overview GHG emissions associated with household energy use in the US, including from food are available in Jones *et al.* 2011 and the associated household emission calculator is available at: http://coolclimate.berkeley.edu/calculator

The primary GHG emissions associated with land-based food production systems (including crop and livestock) include CO_2 from energy consumptive activities, CO_2 resulting from land use and land conversion, N_2O from fertilization of arable land and manure management and CH_4 emissions from ruminant livestock (Nijdam *et al.* 2012).

Rationale for and Summary of the Greenhouse Gas Criteria for Fisheries and Aquaculture

Seafood Watch is proposing to incorporate GHG emission intensity into our science-based methodology for assessing the sustainability of both wild caught and farmed seafood products. GHG accumulation in the Earth's atmosphere and water drives ocean acidification, contributes to sea level rise, affects air and sea temperatures and accelerates climate change. The proposed criterion will evaluate greenhouse gas emissions per edible unit of protein from fisheries and aquaculture operations up to the dock or farm gate (i.e. the point of landing), consistent with the scope Seafood Watch assessments.[3,4] Although a reliable index to define sustainable (or unsustainable) emissions of GHGs does not yet exist, as a baseline, we expect sustainable fisheries and aquaculture operations to have relatively low GHG emissions compared to the demonstrably high emission of some land-based protein production methods. Therefore, in order to classify the GHG emission intensity of seafood products, Seafood Watch initially proposes to relate them to those of intensive poultry and beef production up to the farm gate; with products falling below the median value for poultry production considered as low emission sources, those between the median values for poultry and beef as moderate emission sources, and those above the median value for beef as high emission sources. The advantage of this method is that it provides consumers with information concerning relative impacts of food choices, beyond just seafood, enabling them to compare GHG intensity across edible protein sources Currently, Seafood Watch does not have a scalar metric (as we do for the scored criteria) to score the fisheries energy criterion. GHG emission intensity per edible unit of protein for both fishery and aquaculture products will be calculated using species-specific edible protein estimates based on a literature review compiled by Peter Tyedmers (Dalhousie University, Nova Scotia, Canada). The edible protein estimate is based on the percent edible content and the percent protein content of muscle tissue for each species. Seafood Watch has discussed alternative standardization methods, such as excluding the percent protein content of muscle tissue (because invertebrates often have higher values), using wet weights or standardizing by product form, however, we are retaining the edible unit of protein standardization.

We are basing the farm gate median values for poultry (13 kg CO_2/Kg protein) and beef (134 kg CO_2/Kg protein) production on the supplementary information available from Nijdam *et al.* (2012), incorporating, if possible, a quantitative measure of uncertainty associated with these values, such as suggested in Henriksson et al (2015). The values from Nijdam *et al*. (2012) take into account both energy and non-energy GHG emissions, and include N_2O emissions from fertilization of arable land and manure, CH_4 emissions from ruminant production and manure, and CO_2 from fossil fuel energy. While this source acknowledges the importance of CO_2 emissions from soil cultivation, these emissions are not factored in. This likely will underestimate total GHG emissions. Currently, Seafood

[3] Seafood Watch assesses the ecological impacts on marine and freshwater ecosystems of fisheries and aquaculture operations up to the dock or farm gate. Seafood Watch assessments do not consider all ecological impacts (e.g. land use, air pollution), post-harvest impacts such as processing or transportation, or non-ecological impacts such as social issues, human health or animal welfare.

[4] Seafood Watch will direct users of our recommendations to available post-harvest greenhouse gas emissions calculators. Post-harvest emission assessment is outside the scope of the current standards review.

Watch is investigating comparative measures that incorporate soil CO_2 emissions from land use and land conversion to supplement the values from Nijdam *et al.* (2012).

For the wild-capture fisheries criterion, Seafood Watch proposes using Fuel Use Intensity (FUI) to derive GHG emissions intensity for the target fishery plus an FUI derived GHG intensity factor for bait usage when available. For the aquaculture criterion, we propose a measure of direct farm-level GHG emissions use plus an indirect measure of the GHG emissions associated with feed production.. Emissions associated with feed will be evaluated using a tiered approach, using specific ingredient information where available, and will be based on the dominant feed-ingredient categories (aquatic, crop and land animal) when less information is available. An additional grouping for aquatic ingredients may be possible. Values will be sourced from existing data.

Commercial fisheries and fish farms can achieve both environmental and financial benefits from reducing their energy use and non-energy related GHG emissions. We recognize, however, that data collection related to energy use and non- energy GHG emissions are currently limited, so our aim with these criteria are to incentivize the collection and provision of energy use data and non-energy GHG emission data from both fisheries and aquaculture operations to both track and improve the sustainability of seafood products.

In this first iteration, the Seafood Watch Greenhouse Gas Criteria will be unscored additions to the Seafood Watch criteria, and will be used as companion criteria to our sustainable fisheries and aquaculture assessments.

Wild Capture Fisheries Greenhouse Gas Criterion

MSG guidance -   This section contains the introduction to the Fisheries Energy (GHG Emissions) Criterion. This section is substantively unchanged from the first consultation draft. Feedback on the methodology is requested in the Methods section.

Introduction

Fuel consumption is the primary driver of GHG emissions up to the point of landing for most wild capture fisheries, and is often the main source of emissions through the entire supply chain (Parker 2014, Parker & Tyedmers 2014). As such, measures of fuel consumption in fisheries provide an effective proxy for assessing the GHG emissions, or carbon footprint, of fishery-derived seafood products. As mentioned earlier, Seafood Watch acknowledges that for some fisheries other GHG emissions and other climate forcing agent emissions may be significant, and will consider these additional emissions as information becomes available.

Fuel consumption varies significantly between fisheries targeting different species, employing different gears, and operating in different locales. Fuel use also varies within fisheries over time: consumption increased in many fisheries throughout the 1990s and early 2000s, but has reversed in recent years as fisheries in Europe and Australia have both demonstrated consistent improvement in fuel consumption coinciding with increased fuel costs since 2004. As a result of this variation in fuel use, while it is difficult to estimate fuel consumption of individual fisheries without measuring it directly, generalizations can be made by analyzing previously reported rates in fisheries with similar characteristics. To this end, Robert Parker (PhD Candidate, Institute for Marine and Antarctic

Studies, University of Tasmania, Australia) and Dr. Peter Tyedmers (Dalhousie University, Nova Scotia, Canada) manage a database of primary and secondary analyses of fuel use in fisheries (FEUD – Fisheries and Energy Use Database). Using this database, the draft Seafood Watch wild capture energy criterion is based on "Fuel Use Intensity "(FUI, as liters of fuel consumed per metric ton of round weight landings, L/MT) converted to Green-House Gas Emission Intensity per edible unit of protein (KgCO_2 equivalent/Kg edible protein).

MSG guidance - This section contains the methodology for the Fisheries GHG Emissions Criterion and is substantively unchanged from the first consultation draft, except for the inclusion of example results in Figure 1 and the addition of a section on data collection.

Methods

The sections below describe how GHG emission intensity will be calculated for wild capture fisheries and how data quality will be described.

Part 1: Determining Greenhouse Gas Emission Intensity from Fuel Use Intensity

Fisheries were categorized by species, ISSCAAP (International Standard Statistical Classification of Aquatic Animals and Plants) species class, gear type and FAO area. These codes were used to match each fishery to a subset of records in the FEUD database[5] and each subset was analyzed using R to provide descriptive statistics and a weighted FUI estimate.

The subset of database records used to estimate FUI of each fishery was selected using a ranked set of matching criteria. The best possible match in each case was used. The following ranking of matches were used to choose the subset most appropriate for each fishery's estimate:

1) Records with matching individual species, gear type and FAO area
2) Records with matching individual species and gear type
3) Records with matching species class (ISSCAAP code), gear type and FAO area
4) Records with matching species class (ISSCAAP code) and gear type
5) Records with matching generalized species class (set of ISSCAAP codes), gear type and FAO area
6) Records with matching generalized species class (set of ISSCAAP codes) and gear type

For each fishery, after selecting the most appropriate subset of records, the following information was calculated:

- weighted mean (see below)
- unweighted mean
- standard deviation
- standard error
- median

[5] FEUD currently includes 1,622 data points, covering a wide range of species, gears and regions. The best represented fisheries are those in Europe, those targeting cods and other coastal finfish, and those using bottom trawl gear. Coverage of fisheries from developing countries is limited but increasing. The database focuses on marine fisheries, and includes very few records related to freshwater fishes (except diadromous and catadromous species which are fished primarily in marine environments), marine mammals, or plants.

- minimum value
- maximum value
- number of data points
- number of vessels or observations embedded in data points
- temporal range of data

The weighted mean, intended as the best possible estimate of FUI for each fishery, was calculated and weighted by both number of vessels in each data point and age of the data. To avoid biasing the analyses by large numbers of vessels reported in any one fishery, we used the log of the number of vessels in each data point. For example, the weights of two data points representing 1000 and 10 vessels, respectively, have a ratio of 3:1, rather than 100:1. In addition, data from more recent years were given greater weight (10% difference in weight between subsequent years).

$$w_i = \log10(v_i + 1) \cdot 0.9^{2014-y_i}$$

$$FUI = \sum_{i=1}^{n} \frac{w_i}{\sum_{i=1}^{n} w_i}$$

w_i = the weight given to data point *i*
v_i = the number of vessels reporting in data point *i*
y_i = the fishing year of data point *i*
n = sample size (number of data points included)

The weighted FUI means (L/t) were converted to GHG emission intensity (KgCO_2 equivalent/Kg edible protein) using a conversion factor of 3.12 kg CO_2 emitted per liter of fuel combusted and species specific percent yield and protein content of fish and invertebrate species. The GHG emission factor is based on an assumed fuel mix of bunker C, intermediate fuel oil, and marine diesel oil, and includes emissions from both burning the fuel and all upstream activities (mining, processing and transporting). This conversion factor was calculated using IPCC 2007 GHG intensity factors and EcoInvent 2.0 life cycle inventory database (Parker *et al*. 2014). The species specific percent yield and protein content of muscle data used to convert landed tonnage to edible protein were derived from Peter Tyedmers unpublished database of published and grey literature values.

Part 2: Quality indicators

The amount of data available pertaining to different species and gears varies dramatically, with some classes of fisheries being researched far more than others. As a result, the "quality" of FUI predictions varies. For example, Atlantic cod (*Gadus morhua*) fisheries have been researched extensively, and so FUI estimates for Atlantic cod are relatively reliable. Meanwhile, some fisheries have not been assessed, and so these estimates are based on other similar fisheries instead. Each FUI estimate generated here was given three quality ratings:

- a ***match quality*** indicator, reflecting the degree to which records in the database matched the species, gear and region criteria for each fishery. The species match is particularly reflected here, as all estimates match the gear type. *Low* = records match the generalized species class (e.g. crustaceans, molluscs); *medium* = records match the species class (e.g. lobsters); *high* = records match the individual species (e.g. Atlantic cod); *very high* = records match the individual species, gear type and region (*e.g.* Atlantic cod caught using longlines in FAO area 27). Table 2 shows a breakdown of assessed fisheries on the basis of the match quality.

Table 2. Criteria used to match Seafood Watch fisheries with FEUD records.

Matching factors	Number of FUI estimates
Individual species, gear type and FAO area	21
Individual species and gear type	15
Species class (ISSCAAP code), gear type and FAO area	64
Species class (ISSCAAP code) and gear type	54
Generalized species class (set of ISSCAAP codes), gear type and FAO area	45
Generalized species class (set of ISSCAAP codes) and gear type	38

- a ***temporal quality*** indicator, reflecting the proportion of data points from years since 2000. *Very low* = all records are from before 2000; *low* = <25% of records are from 2000 on; *medium* = 25-49% of records are from 2000 on; *high* = 50-74% of records are from 2000 on; *very high* = 75% or more of records are from 2000 on.

- a ***subjective quality*** indicator reflects the confidence of the author in each estimate, based on the match criteria, temporal range, variability in the data, sample size, types of sources, and general understanding of typical patterns in FUI.

The subjective quality indicator is a good indication of the relative reliability of each estimate. It takes into account the range of data used, the method of weighting, and the degree to which the estimate reflects previous assessments of FUI in fisheries around the world. There are instances where the subjective quality indicator does not agree with the other quality rankings. For example, some estimates include a large number of older data points, and are therefore given a low temporal quality rating, but because the weighting method used gives more influence to more recent data points, the estimate closely reflects recent findings and is therefore given a high rating.

Data Collection

As part of the assessment process, the analyst will search for and request additional information on Fuel Use for the fishery under assessment to supplement and add to data in the Fuel Use Intensity Database. The analyst will also research the potential for other GHG emissions and non-GHG emissions of substances, like black carbon, which have high global warming potentials.

Communicating GHG intensity values for wild capture fisheries

As stated in the Rationale section, the proposed Seafood Watch GHG Criteria will be unscored additions to our sustainable seafood assessments. GHG intensity values for seafood will be compared to median GHG intensity values for land based protein production: poultry (considered a medium emission protein) and beef (considered a high emission protein). See the Rationale section for more information. Any method of communicating a GHG Intensity value for fisheries based on the FUI estimates generated here should take into account three things:

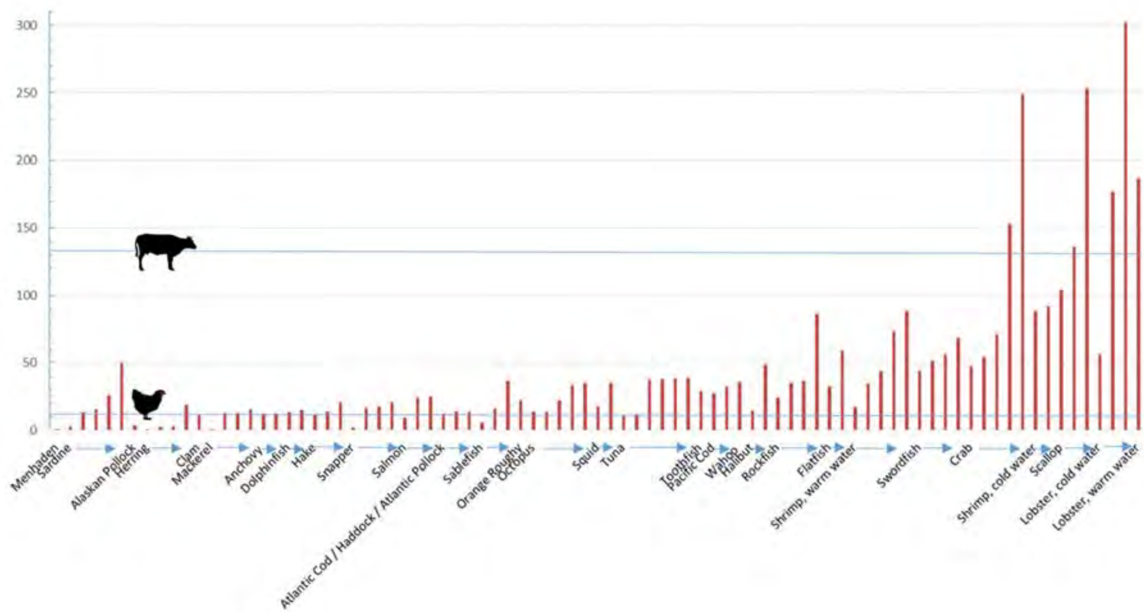
a) the estimates are based on fuel inputs to fisheries only, and, while fuel often accounts for the majority of life cycle carbon emissions, they need to be viewed in the context of the total supply chain. Most importantly, products that are associated with a high amount of product waste and loss during processing, or that are transported via air freight, are likely to have high sources of emissions beyond fuel consumption.

b) the quality of estimates varies, as is reflected in the quality indicators provided. Scoring fisheries with better quality estimates is easier than scoring predicted FUI of fisheries based on similar fisheries. For that reason, it may be justifiable to score only fisheries with a 'high' quality estimate, or to indicate that some scores are based on expected FUI rather than actual reported values.

c) the value should be expressed relative to some base value, reflecting relative performance of similar fisheries and/or alternative fishery products and/or alternative protein sources.

An example of how a subset of fisheries would fall relative to poultry and beef is shown in Figure 1 below.

Figure 1: GHG Intensity Values for a subset of Seafood Watch recommendations, based on work performed by Robert Parker using the FEUD database. Fisheries represented by multiple gear types are shown by multiple red bars. Numerical value of median emission intensity for poultry production and beef production are shown as horizontal lines. Beef and poultry values were derived from Nijdam et al (2012).



Aquaculture Greenhouse Gas Emission Criterion

MSG guidance - This section contains the introduction to the Aquaculture GHG emission Criterion.

Introduction

Feed production and on-site farm energy use are the two major drivers of GHG emissions from aquaculture operations up to the farm gate (Pelletier *et al.* 2011). For fed systems (fed systems comprise 69% of global aquaculture production (FAO 2014)), feed production is often the greater of these two drivers, particularly for net-pen systems where important processes such as water exchange, aeration and temperature regulation are provided naturally by the ecosystem (Pelletier *et al.* 2011). In pond production systems, large variations in the rate of water exchange (i.e. the volume of pumping) and aeration practices mean that farm-level energy use varies greatly between species and regions. Farm-level energy use is often the primary driver of GHG emissions for tank-based recirculating systems which require energy to run all life support and control systems (Parker 2012b) (Samuel-Fitwi *et al.* 2013). In stark contrast, farmed bivalves and aquatic plants (which represent less than 31% of global aquaculture production (FAO 2014)), require few external inputs and have low energy demand (Pelletier *et al.* 2011).

Farm location may also be a significant factor influencing total GHG emissions from aquaculture operations due to differences in the regional mix of energy sources used to generate electricity. Farms that are run primarily on fossil fuel based electricity (such as coal or oil) will have much higher total GHG emissions than those run on renewable energy sources (such as hydropower, wind, geothermal or solar) or on nuclear energy (Parker 2012b).

Additional GHG emissions may result from sources other than farm level energy use and feed production, such as from energy use associated with grow out infrastructure and smolt production and from non-energy emissions of CH_4 and N_2O from ponds (as discussed in the above section “Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production”).

Seafood Watch recognizes that energy use varies greatly among different production systems and can be a major impact category for some aquaculture operations. It is noteworthy that improving practices for some of the Aquaculture Assessment Criteria may lead to more energy intensive production systems (e.g. where our recommendations are better for energy-intensive closed recirculation systems than for open systems). Seafood Watch also recognizes (as mentioned in the above section “Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production”), that non-energy emissions associated with aquaculture production may be significant but are not always well described or quantified.

MSG guidance - This section contains the methodology for the Aquaculture GHG Emissions Criterion. This criterion is less well developed than the fisheries criterion, primarily due the greater complexity of assessing the GHG emissions of aquaculture operations and the very limited data available. Changes made to this section since the first public consultation include 1) a tiered approach to evaluating GHG emissions associated with feed based on data availability 2) data from a literature review of farm level energy use and feed energy 3) factoring in non-energy GHG emissions from both feed and farm level activities where this data is available 4) Separation out of sections on data collection and communicating GHG intensity values. Given the paucity of data, Seafood Watch will continue to collect and actively solicit information on GHG emissions associated with feed production and farm level activities. In particular, Seafood Watch will seek out information on the GHG emissions associated with specific feed ingredients.

Methods

Seafood Watch is currently developing the methodology for assessing GHG emissions from aquaculture operations up to the farm gate. This methodology will include an assessment of the cumulative GHG emissions from feed use (primarily feed ingredient production, processing and potentially transport) as well as farm-level emissions from energy use.

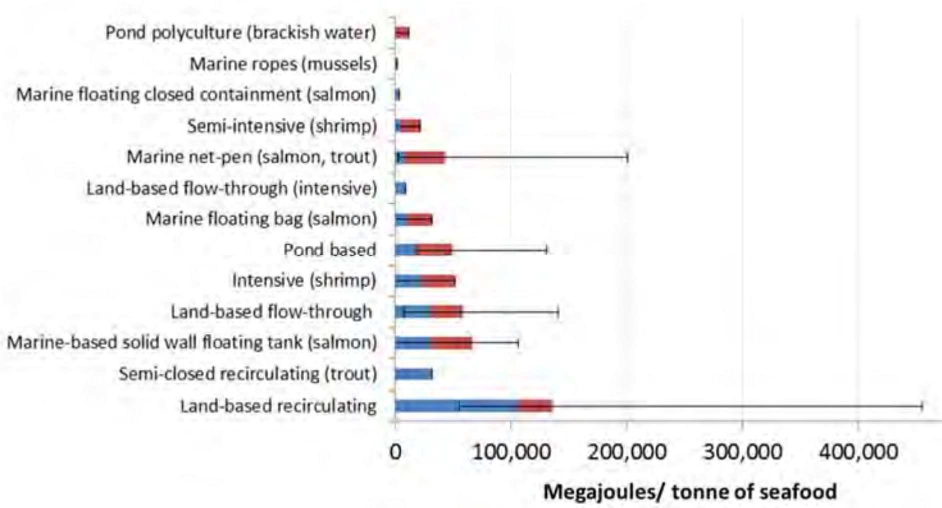
We propose using a tiered approach to evaluating the feed contribution to GHG emissions. Where the specific origins of feed ingredients can be identified, it may be possible to determine the GHG emissions with high accuracy. When the specific ingredients are unknown, we propose basing the feed component on GHG emission estimates of dominant feed ingredient groups; i.e. aquatic (fishmeal and oil), crop and land animal (from Pelletier *et al*. 2009 and from additional sources) along with corresponding estimates of feed types and quantities fed by operations under assessment. We recognize that there may be significant differences in GHG emission values between the feeds in each of these groups, notably within the aquatic feed group (such as between a feed based primarily on fishmeal sourced from bycatch from a regional fishery on the low end of the spectrum and a feed sourced primarily from a distant reduction fishery), and we will break out the feeds in these groups where possible.

For the farm-level component, Seafood Watch proposes quantifying GHG emissions associated with pumping, aeration and other energy consumptive activities. Seafood Watch will draw data from existing studies and data gathered directly from aquaculture operations. As an initial step, Seafood Watch has compiled information from Life Cycle Analysis (LCA) studies and other sources on farm level energy use and energy use associated with feeds (carried out by Keegan McGrath). The results are summarized in Figure 2. When data are not available to finely estimate GHG emissions for each component (feed and farm-level energy), Seafood Watch proposes defaulting to GHG estimates based on the most closely related species type, production type and the energy mix most commonly used in the region under assessment.

As with the Fisheries criterion, all emissions estimates will be standardized to GHG Intensity per edible unit of protein (KgCO_2 equivalent/Kg edible protein).

The total GHG emissions will be obtained by summing the GHG emissions from feed ingredients (Part 1 below) and farm-level energy use (Part 2 below).

Figure 2: Energy use associated with aquaculture feeds (red bars) and farm level activities (blue bars) for a variety of species and production methods in units of megajoules/tonne of seafood, drawn from LCA studies and other information sources. Literature review carried out by Keegan McGrath. These data will be transformed into GHG Intensity per unit of edible protein (KgCO2 equivalent/Kg edible protein) when applied to this criterion.



Part 1: GHG Emissions associated with feed ingredients/ Energy Return on Investments

As mentioned above, Seafood Watch proposes using a tiered approach to quantify the GHG Intensity (KgCO_2 equivalent/Kg edible protein) of feed ingredients. The tiers are based on the level of information available for the species and production system in the region or country under assessment. The first tier will be used when Seafood Watch can determine the specific feed ingredient mix and can determine associated GHG emission intensity values associated with the primary components (ideally taking into account the energy and non-energy emissions associated with the feed). Data on the specific feed ingredient mix will be requested at the start of the assessment process with the goal of using this first tier. Seafood Watch will employ the second tier when we are unable to determine the specific feed ingredient mix, but can determine the percentage of the three dominant ingredient types (aquatic, crop and land animal). When significant differences in GHG emissions can be clarified between feeds used from the dominant ingredient types, we will use a hybrid of the first and second tiers.

Factored into the GHG Intensity calculation for both tiers (and the hybrid tier) is the Economic Feed Conversion Ratio (eFCR), the total amount of feed used to produce a given output of harvested fish biomass, taking into account loss of feed via escapes, death, predation, disease, environmental disasters and other losses. In addition to the GHG Intensity value, Seafood Watch will provide an estimate of confidence in the value (whether this will be a numerical value or a scalar value is being discussed)

GHG Emissions for Feed Ingredient Inputs:

Tier 1
Cumulative GHG emission from feed = Total of ingredient specific GHG emission values* x eFCR

* Depending on the data collected by the analyst, this will be the total of ingredient specific GHG emission values or a total value for a feed formulation. Seafood Watch is currently investigating the derivation method for calculating feed specific or formulation specific GHG values, and input for how best to accomplish this is requested during this second public consultation process.

Tier 2
a) Aquatic ingredient inclusion rate = _____ %
b) Crop ingredient inclusion rate = _____ %
c) Land animal ingredient inclusion rate = _____ %
d) Economic Feed Conversion Ratio (eFCR) = _____

Cumulative GHG emissions from feed (kg CO_2-eq/t) = [(a x 2158) + (b x 1007) + (c x 4138)] x (d)[6]

For all tiers: Total feed cumulative GHG emissions (expressing edible return on investment) = ________ Kg CO_2 equivalents/Kg of edible protein

Kgs of edible protein (above) will be derived from metric tons of harvested fish using two factors:
- the species specific edible percentage and
- the species specific protein percentage of muscle tissue.

These percentages will be drawn from Peter Tyedmers' unpublished database.

Part 2: Farm-Level Energy Use

For this component Seafood Watch proposes to quantify the GHG emissions associated with direct farm-level energy use. The primary energy consumptive farm activities are water pumping and aeration but also might include activities such as temperature regulation, filtration, feed and chemical dispersal and harvesting. We acknowledge that additional energy consumptive activities are associated with aquaculture production, such as from grow out infrastructure and smolt production, but are not included in our assessment. We propose the following assessment methods, depending on data availability. For each of the options, Seafood Watch intends to provide an

[6] Mean values for the feed ingredient groups were derived from Pelletier *et al.* 2009, using the methodology described in Pelletier *et al.* 2010.

estimate of confidence in the value (whether this will be a numerical value or a scalar value is under consideration)

Farm-level data
As the most accurate measure, Seafood Watch aims to obtain farm-level information on total energy use as well as the energy mix (e.g. diesel versus electricity, but also the regional mix of fuels used for electricity generation) specific to the aquaculture operations under assessment in order to estimate farm-level GHG emissions. In addition to farm level energy, Seafood Watch aims to obtain information on non-energy GHG emissions produced at the farm level. Such non-energy emissions include N_20 and CH_4 from ponds (see the discussion in the section above: “Overview of Greenhouse Gas Emissions from Fisheries, Aquaculture and Land-based Food Production”). As with the feed component, GHG emissions will be standardized to the Kgs of edible protein.

Energy use values from scientific and grey Literature
Where farm-level information is not available, Seafood Watch proposes to model GHG emissions based on production method, species and farm-level energy use data and non-energy GHG emissions published in peer reviewed journals and available from grey literature. To estimate GHG emissions, this farm-level energy use data will be synthesized with data on the most common mix of fuels used for electricity generation in the region of assessment. As with the feed component, GHG emissions will be standardized to the Kgs of edible protein.

Relative energy use from water pumping and aeration
When farm-level or literature data are unavailable, Seafood Watch has developed the following tables to classify energy use from water pumping and aeration on a relative scale, which can be translated to relative GHG emission intensity. This method does not factor in non-energy GHG emissions:

Water Pumping
A crude estimated measure of the energy used in pumping water

Use pumping data or descriptions to select score value from the table below.

	Water pumping characteristics[7]	**Score**
Zero	No significant water pumping, e.g. cages, passive fill ponds, gravity fed tanks/ponds/raceways.	5
Low	Static ponds	4
Low-Moderate	Harvest discharge or occasional exchange	3
Moderate	Low daily exchange rate >0 to 3%	2
Moderate-High	Significant daily water exchanges 3-10%	1
High	Large daily water exchanges, recirculation systems >10%	0

Note - low energy use is given a high score

Energy use (pumping) score = ______ (range 0-5)

Record water pumping data here if available:
Pumped volume per metric ton of product _______ m^3 MT^{-1}]
Average pumping head height _______ m
Average pump power _______ KW or HP

[7] As a guide, Low = <1000 m^3/MT, Low-Moderate = 1000 – 5,000 m^3/MT, Moderate = 5,000 – 20,000 m^3/MT, Moderate-High = 20,000-150,000 m^3/MT, High = >150,000 m^3/MT

Aeration
A crude estimated measure of the energy used for aeration

	Aeration characteristics[8] or average duration	Score
Zero	Zero	5
Low	Minimal aeration	4
Low-Moderate	Low power and/or short duration <6h/day	3
Moderate	Moderate power and/or 6-12h/day	2
Moderate-High	Moderate-high power and/or 12-18h/day	1
High	High power and/or >18 hours per day	0

Note low energy use is given a high score

Energy use (aeration) score = _____ (range 1-5)

Record aeration data here if available:
Aeration energy use = ______ kW·h per MT
Average aeration duration per day ______
Aerator power ______ kWh or HP

Overall Farm-level Calculations

Farm Energy Use (FEU) = Pumping + aeration
Farm Energy Use Score (FEU) = ______ (range 0-10)

If the above method is used, Seafood Watch will determine a conversion to GHG emissions in order to combine this measure with the feed GHG measure.

Data Collection

As mentioned in the above methods sections, the analyst will search for and request additional information on 1) farm level GHG emissions (both energy and non-energy GHG emissions), 2) the country/regional energy mix or if off the grid – the energy sources generally used for that production system and 3) information on feed composition and GHG values associated with the ingredients used.

Communicating GHG intensity values for aquaculture operations

As stated in the Rationale section, the proposed Seafood Watch GHG Criteria will be unscored additions to our sustainable seafood assessments. GHG intensity values for seafood will be compared to median GHG intensity values for land based protein production: poultry (considered a medium emission protein) and beef (considered a high emission protein). See the Rationale section for more information. Any method of communicating a GHG Intensity value for aquaculture will need to be transparent about the GHGs included in the derived GHG value as well as those emissions which are likely significant but which are not included in the assessment due to lack of data.

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[8] As a guide, low = <500 kW·h per MT, Low-Moderate = 500 – 1,500 kW·h per MT, Moderate = 1,500-3,000 kW·h per MT, Moderate-High = 3,000 – 4,500 kW·h per MT, High = >4,500 kW·h per MT (values are for example only (based on Boyd et al, 2007) and need refining)

Summary of Changes Made Since the First and Second Public Consultation

Several changes were made to the Criteria for Fisheries and Aquaculture as a result of the first consultation process feedback from the Seafood Watch Technical Advisory Committees, feedback solicited during an expert webinar and from collaborative work with Peter Tyedmers, who is both on the Seafood Watch Technical Advisory Committee for Aquaculture and was involved in the expert webinar. No substantive changes were made as a result of the second consultation process. Seafood Watch would like to thank and acknowledge everyone who provided feedback. These revisions are briefly described in bulleted format here:

- Revised the Guiding Principle to acknowledge the contribution of GHGs to the acceleration of climate change and to acknowledge that GHG emissions from food production are a significant fraction of anthropogenic GHG emissions.
- Included an overview of the range of GHG emissions associated with fisheries and aquaculture in the introductory information. The purpose of this is to acknowledge the range of potential GHGs associated with seafood production and provide for the assessment of the full range of emissions as information becomes available.
- Provided additional information about the GHG emissions included in our approach comparing up to the farm gate/dock emissions from seafood to land-based proteins. In addition we've clarified that we will be using the median values for comparative protein GHG intensities.
- Included example results for the Fisheries Criterion
- Created a tiered approach to evaluate GHG emissions associated with feed, based on data availability
- Included data obtained from a literature review of farm level energy use and feed energy
- Factored in non-energy GHG emissions from both feed and farm level activities when these data are available.
- Added separate sections on data collection both the fisheries and aquaculture criteria
- Added separate section on communicating GHG intensity values for aquaculture.

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Review

Energy use in Recirculating Aquaculture Systems (RAS): A review

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Highlights

- RAS energy use is a drawback, increasing operational costs and environmental impact.
- RAS design should comprehend water and energy use, waste discharge and productivity.
- Economic and environmental sustainable RAS is achieved quantifying all energy flows.
- Fossil based fuels are less cost-effective and renewable energies of potential use.

Abstract

Recirculating aquaculture systems (RASs) are intensive fish production systems, with reduced use of water and land. However, their high energy requirement is a drawback, which increases both operational costs and the potential impacts created by the use of fossil fuels. Energy use in RAS has been studied indirectly and/or mentioned in several publications. Nevertheless, its importance and impacts have not been studied. In aiming to achieve economic and environmentally sustainable production a compromise has to be found between water use, waste discharge, energy consumption and productivity. The current review discusses published studies about energy use and RAS designs efficiencies. Moreover, with the aim of making an industry baseline study a survey about the energy use in commercial scale RAS was conducted. The design of more efficient and less energy dependent RAS is presented, including optimized unit processes, system integration and equipment selection. The main conclusions are: fossil based fuels are less cost-effective than renewable energies; energy is of little concern for the majority of the industry, and renewable energies are of potential use in RAS.

Previous

Next

Keywords

Energy use; Recirculating aquaculture systems; Environment; Optimized-designs; Cost-effectiveness; Sustainability

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Emissions Gap Report 2019

Executive Summary

EXHIBIT
D-7

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Emissions Gap Report 2019

Executive summary

Executive summary – Emissions Gap Report 2019

Introduction

This is the tenth edition of the United Nations Environment Programme (UNEP) Emissions Gap Report. It provides the latest assessment of scientific studies on current and estimated future greenhouse gas (GHG) emissions and compares these with the emission levels permissible for the world to progress on a least-cost pathway to achieve the goals of the Paris Agreement. This difference between "where we are likely to be and where we need to be" has become known as the 'emissions gap'.

Reflecting on the ten-year anniversary, a summary report, entitled Lessons from a decade of emissions gap assessments, was published in September for the Secretary-General's Climate Action Summit.

The summary findings are bleak. Countries collectively failed to stop the growth in global GHG emissions, meaning that deeper and faster cuts are now required. However, behind the grim headlines, a more differentiated message emerges from the ten-year summary. A number of encouraging developments have taken place and the political focus on the climate crisis is growing in several countries, with voters and protestors, particularly youth, making it clear that it is their number one issue. In addition, the technologies for rapid and cost-effective emission reductions have improved significantly.

As in previous years, this report explores some of the most promising and applicable options available for countries to bridge the gap, with a focus on how to create transformational change and just transitions. Reflecting on the report's overall conclusions, it is evident that incremental changes will not be enough and there is a need for rapid and transformational action.

The political context in 2019 has been dominated by the United Nations Secretary-General's Global Climate Action Summit, which was held in September and brought together governments, the private sector, civil society, local authorities and international organizations.

The aim of the Summit was to stimulate action and in particular to secure countries' commitment to enhance their nationally determined contributions (NDCs) by 2020 and aim for net zero emissions by 2050.

According to the press release at the end of the Summit, around 70 countries announced their intention to submit enhanced NDCs in 2020, with 65 countries and major subnational economies committing to work towards achieving net zero emissions by 2050. In addition, several private companies, finance institutions and major cities announced concrete steps to reduce emissions and shift investments into low-carbon technologies. A key aim of the Summit was to secure commitment from countries to enhance their NDCs, which was met to some extent, but largely by smaller economies. With most of the G20 members visibly absent, the likely impact on the emissions gap will be limited.

As regards the scientific perspective, the Intergovernmental Panel on Climate Change (IPCC) issued two special reports in 2019: the Climate Change and Land report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems, and the Ocean and Cryosphere in a Changing Climate report. Both reports voice strong concerns about observed and predicted changes resulting from climate change and provide an even stronger scientific foundation that supports the importance of the temperature goals of the Paris Agreement and the need to ensure emissions are on track to achieve these goals.

This Emissions Gap Report has been prepared by an international team of leading scientists, assessing all available information, including that published in the context of the IPCC special reports, as well as in other recent scientific studies. The assessment production process has been transparent and participatory. The assessment methodology and preliminary findings were made available to the governments of the countries specifically mentioned in the report to provide them with the opportunity to comment on the findings.

1. GHG emissions continue to rise, despite scientific warnings and political commitments.

- GHG emissions have risen at a rate of 1.5 per cent per year in the last decade, stabilizing only briefly between 2014 and 2016. Total GHG emissions, including from land-use change, reached a record high of 55.3 $GtCO_2e$ in 2018.

- Fossil CO_2 emissions from energy use and industry, which dominate total GHG emissions, grew 2.0 per cent in 2018, reaching a record 37.5 $GtCO_2$ per year.

- There is no sign of GHG emissions peaking in the next few years; every year of postponed peaking means that deeper and faster cuts will be required. By 2030, emissions would need to be 25 per cent and 55 per cent lower than in 2018 to put the world on the least-cost pathway to limiting global warming to below 2˚C and 1.5°C respectively.

- Figure ES.1 shows a decomposition of the average annual growth rates of economic activity (gross domestic product – GDP), primary energy use, energy use per unit of GDP, CO_2 emissions per unit of energy and GHG emissions from all sources for Organisation for Economic Co-operation and Development (OECD) and non-OECD members.

- Economic growth has been much stronger in non-OECD members, growing at over 4.5 per cent per year in the last decade compared with 2 per cent per year in OECD members. Since OECD and non-OECD members have had similar declines in the amount of energy used per unit of economic activity, stronger economic growth means that primary energy use has increased much faster in non-OECD members (2.8 per cent per year) than in OECD members (0.3 per cent per year).

- OECD members already use less energy per unit of economic activity, which suggests that non-OECD members have the potential to accelerate improvements even as they grow, industrialize and urbanize their economies in order to meet development objectives.

- While the global data provide valuable insight for understanding the continued growth in emissions, it is necessary to examine the trends of major emitters to gain a clearer picture of the underlying trends (figure ES.2). Country rankings change dramatically when comparing total and per capita emissions: for example, it is evident that China now has per capita emissions in the same range as the European Union (EU) and is almost at a similar level to Japan.

- Consumption-based emission estimates, also known as a carbon footprint, that adjust the standard territorial emissions for imports and exports, provide policymakers with a deeper insight into the role of consumption, trade and the interconnectedness of countries. Figure ES.3 shows that the net flow of embodied carbon is from developing to developed countries, even as developed countries reduce their territorial emissions this effect is being partially offset by importing embodied carbon, implying for example that EU per capita emissions are higher than Chinese when consumption-based emissions are included. It should be noted that consumption-based emissions are not used within the context of the United Nations Framework Convention on Climate Change (UNFCCC).

Figure ES.1. Average annual growth rates of key drivers of global CO_2 emissions (left of dotted line) and components of greenhouse gas emissions (right of dotted line) for OECD and non-OECD members

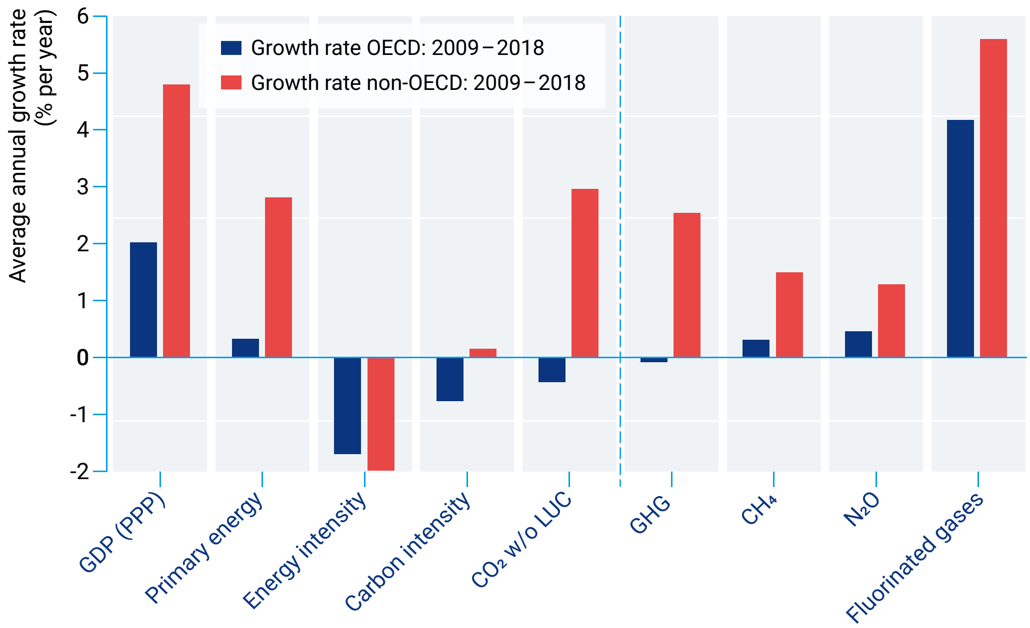
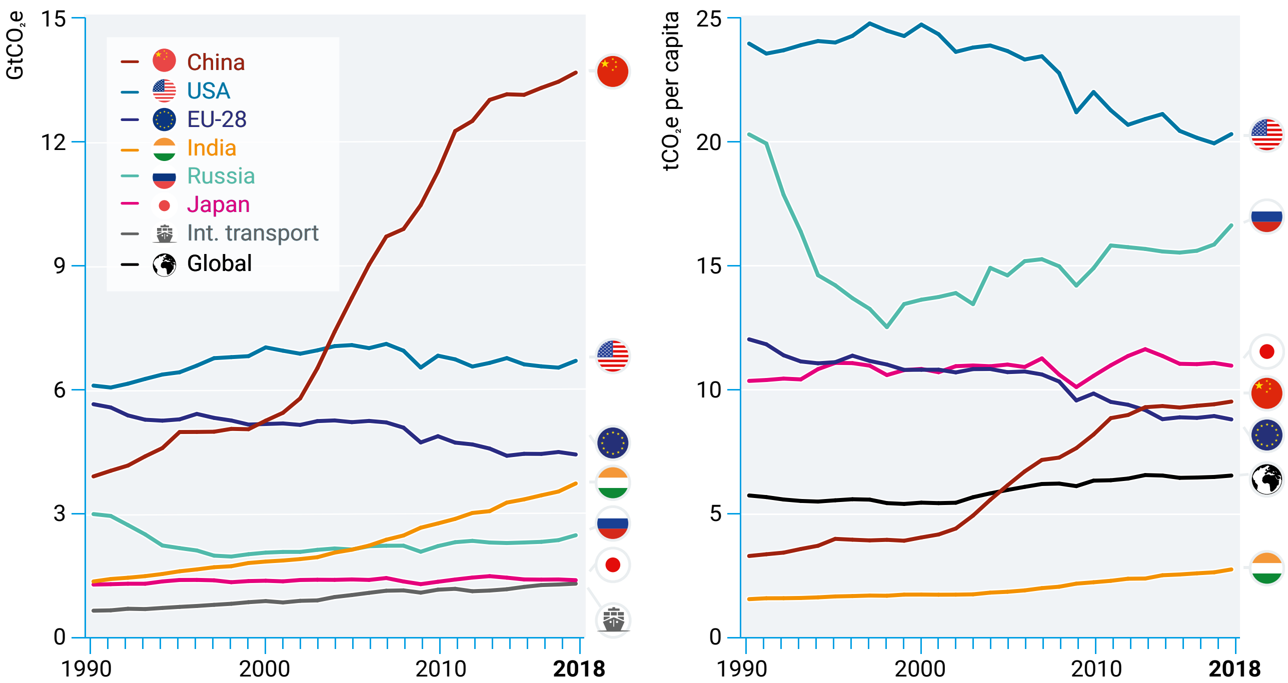


Figure ES.2. Top greenhouse gas emitters, excluding land-use change emissions due to lack of reliable country-level data, on an absolute basis (left) and per capita basis (right)



2. G20 members account for 78 per cent of global GHG emissions. Collectively, they are on track to meet their limited 2020 Cancun Pledges, but seven countries are currently not on track to meet 2030 NDC commitments, and for a further three, it is not possible to say.

- As G20 members account for around 78 per cent of global GHG emissions (including land use), they largely determine global emission trends and the extent to which the 2030 emissions gap will be closed. This report therefore pays close attention to G20 members.

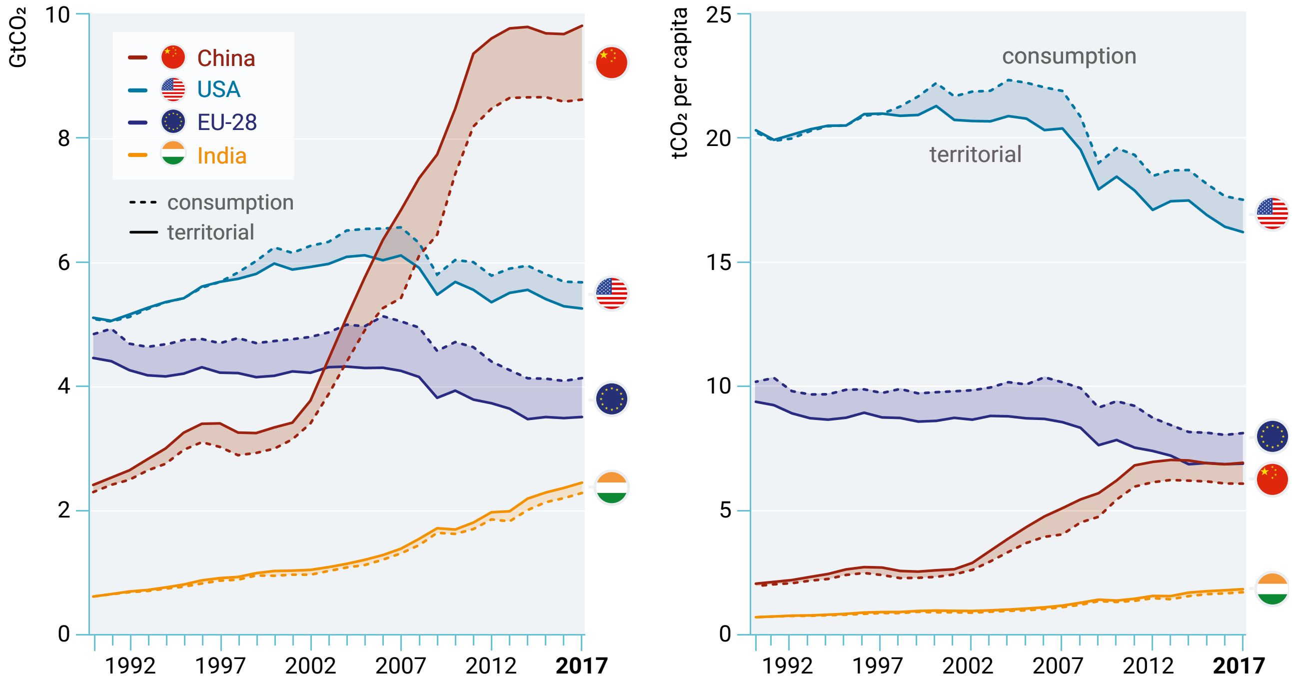
- G20 members with 2020 Cancun Pledges are collectively projected to overachieve these by about 1 $GtCO_2e$ per year. However, several individual G20 members (Canada, Indonesia, Mexico, the Republic of Korea, South Africa, the United States of America) are currently projected to miss their Cancun Pledges or will not achieve them with great certainty. Argentina, Saudi Arabia and Turkey have not made 2020 pledges and pledges from several countries that meet their targets are rather unambitious.

- Australia is carrying forward their overachievement from the Kyoto period to meet their 2020 Cancun Pledge and counts cumulative emissions between 2013 and 2020. With this method, the Australian Government projects that the country will overachieve its 2020 pledge. However, if this 'carry-forward' approach is not taken, Australia will not achieve its 2020 pledge.

- On the progress of G20 economies towards their NDC targets, six members (China, the EU28, India, Mexico, Russia and Turkey) are projected to meet their unconditional NDC targets with current policies. Among them, three countries (India, Russia and Turkey) are projected to be more than 15 per cent lower than their NDC target emission levels. These results suggest that the three countries have room to raise their NDC ambition significantly. The EU28 has introduced climate legislation that achieves at least a 40 per cent reduction in GHG emissions, which the European Commission projects could be overachieved if domestic legislation is fully implemented in member states.

- In contrast, seven G20 members require further action of varying degree to achieve their NDC: Australia, Brazil, Canada, Japan, the Republic of Korea, South Africa and the United States of

Figure ES.3. CO_2 emissions allocated to the point of emissions (territorial) and the point of consumption, for absolute emissions (left) and per capita (right)



America. For Brazil, the emissions projections from three annually updated publications were all revised upward, reflecting the recent trend towards increased deforestation, among others. In Japan, however, current policy projections have been close to achieving its NDC target for the last few years.

- Studies do not agree on whether Argentina, Indonesia and Saudi Arabia are on track to meet their unconditional NDCs. For Argentina, recent domestic analysis that reflects the most recent GHG inventory data up to 2016 projects that the country will achieve its unconditional NDC target, while two international studies project that it will fall short of its target. For Indonesia, this is mainly due to uncertainty concerning the country's land use, land-use change and forestry (LULUCF) emissions. For Saudi Arabia, the limited amount of information on the country's climate policies has not allowed for further assessments beyond the two studies reviewed.

- Some G20 members are continuously strengthening their mitigation policy packages, leading to a downward revision of current policy scenario projections for total emissions over time. One example is the EU, where a noticeable downward shift has been observed in current policy scenario projections for 2030 since the 2015 edition of the Emissions Gap Report.

3. Although the number of countries announcing net zero GHG emission targets for 2050 is increasing, only a few countries have so far formally submitted long-term strategies to the UNFCCC.

- An increasing number of countries have set net zero emission targets domestically and 65 countries and major subnational economies, such as the region of California and major cities worldwide, have committed to net zero emissions by 2050. However, only a few long-term strategies submitted to the UNFCCC have so far committed to a timeline for net zero emissions, none of which are from a G20 member.

- Five G20 members (the EU and four individual members) have committed to long-term zero emission targets, of which three are currently in the process of passing legislation and two have recently passed legislation. The remaining 15 G20 members have not yet committed to zero emission targets.

Table ES.1. Global total GHG emissions by 2030 under different scenarios (median and 10th to 90th percentile range), temperature implications and the resulting emissions gap

Scenario (rounded to the nearest gigaton)	Number of scenarios in set	Global total emissions in 2030 [$GtCO_2e$]	Estimated temperature outcomes			Closest corresponding IPCC SR1.5 scenario class	Emissions Gap in 2030 [$GtCO_2e$]		
			50% probability	66% probability	90% probability		Below 2.0°C	Below 1.8°C	Below 1.5°C in 2100
2005-policies	6	**64** (60–68)							
Current policy	8	**60** (58–64)					**18** (17–23)	**24** (23–29)	**35** (34–39)
Unconditional NDCs	11	**56** (54–60)					**15** (12–18)	**21** (18–24)	**32** (29–35)
Conditional NDCs	12	**54** (51–56)					**12** (9–14)	**18** (15–21)	**29** (26–31)
Below 2.0°C (66% probability)	29	**41** (39–46)	Peak: 1.7-1.8°C In 2100: 1.6-1.7°C	**Peak:** **1.9-2.0°C** **In 2100:** **1.8-1.9°C**	Peak: 2.4-2.6°C In 2100: 2.3-2.5°C	Higher-2°C pathways			
Below 1.8°C (66% probability)	43	**35** (31–41)	Peak: 1.6-1.7°C In 2100: 1.3-1.6°C	**Peak:** **1.7-1.8°C** **In 2100:** **1.5-1.7°C**	Peak: 2.1-2.3°C In 2100: 1.9-2.2°C	Lower-2°C pathways			
Below 1.5°C in 2100 and peak below 1.7°C (both with 66% probability)	13	**25** (22–31)	Peak: 1.5-1.6°C In 2100: 1.2-1-3°C	**Peak:** **1.6-1.7°C** **In 2100:** **1.4-1.5°C**	Peak: 2.0-2.1°C In 2100: 1.8-1.9°C	1.5°C with no or limited overshoot			

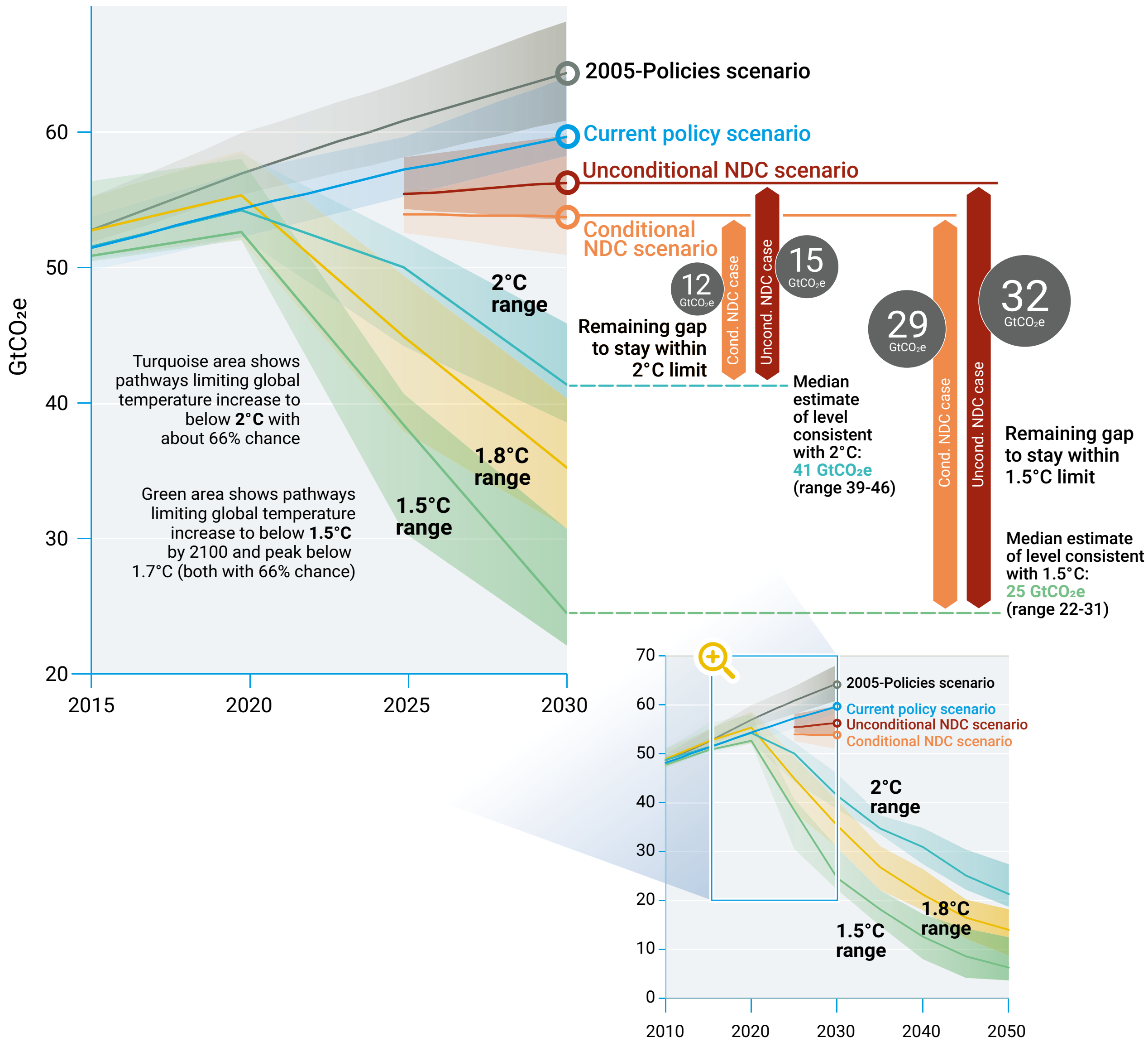
4. The emissions gap is large. In 2030, annual emissions need to be 15 $GtCO_2e$ lower than current unconditional NDCs imply for the 2°C goal, and 32 $GtCO_2e$ lower for the 1.5°C goal.

- Estimates of where GHG emissions should be in 2030 in order to be consistent with a least-cost pathway towards limiting global warming to the specific temperature goals have been calculated from the scenarios that were compiled as part of the mitigation pathway assessment of the IPCC Special Report on Global Warming of 1.5°C report.

- This report presents an assessment of global emissions pathways relative to those consistent with limiting warming to 2°C, 1.8°C and 1.5°C, in order to provide a clear picture of the pathways that will keep warming in the range of 2°C to 1.5°C. The report also includes an overview of the peak and 2100 temperature outcomes associated with different likelihoods. The inclusion of the 1.8°C level allows for a more nuanced interpretation and discussion of the implication of the Paris Agreement's temperature targets for near-term emissions.

- The NDC scenarios of this year's report are based on updated data from the same sources used for the current policies scenario and is provided by 12 modelling groups. Projected NDC levels for some countries, in particular China and India, depend on recent emission trends or GDP growth projections that are easily outdated in older studies. Thus, studies that were published in 2015, before the adoption of the Paris Agreement, have been excluded in this year's update. Excluding such studies has had little impact

Figure ES.4. Global GHG emissions under different scenarios and the emissions gap by 2030



on the projected global emission levels of the NDC scenarios, which are very similar to those presented in the UNEP Emissions Gap Report 2018.

- With only current policies, GHG emissions are estimated to be 60 $GtCO_2e$ in 2030. On a least-cost pathway towards the Paris Agreement goals in 2030, median estimates are 41 $GtCO_2e$ for 2°C, 35 $GtCO_2e$ for 1.8°C, and 25 $GtCO_2e$ for 1.5°C.
- If unconditional and conditional NDCs are fully implemented, global emissions are estimated to reduce by around 4 $GtCO_2e$ and 6 $GtCO_2e$ respectively by 2030, compared with the current policy scenario.
- The emissions gap between estimated total global emissions by 2030 under the NDC scenarios and under pathways limiting warming to below 2°C and 1.5°C is large (see Figure ES.4). Full implementation of the unconditional NDCs is estimated to result in a gap of 15 $GtCO_2e$ (range: 12–18 $GtCO_2e$) by 2030, compared with the 2°C scenario. The emissions gap between implementing the unconditional NDCs and the 1.5°C pathway is about 32 $GtCO_2e$ (range: 29–35 $GtCO_2e$).
- The full implementation of both unconditional and conditional NDCs would reduce this gap by around 2–3 $GtCO_2e$.
- If current unconditional NDCs are fully implemented, there is a 66 per cent chance that warming will be limited to 3.2°C by the end of the century. If conditional NDCs are also effectively implemented, warming will likely reduce by about 0.2°C.

5. Dramatic strengthening of the NDCs is needed in 2020. Countries must increase their NDC ambitions threefold to achieve the well below 2°C goal and more than fivefold to achieve the 1.5°C goal.

- The ratchet mechanism of the Paris Agreement foresees strengthening of NDCs every five years. Parties to the Paris Agreement identified 2020 as a critical next step in this process, inviting countries to communicate or update their NDCs by this time. Given the time lag between policy decisions and associated emission reductions, waiting until 2025 to strengthen NDCs will be too late to close the large 2030 emissions gap.

- The challenge is clear. The recent IPCC special reports clearly describe the dire consequences of inaction and are backed by record temperatures worldwide along with enhanced extreme events.

- Had serious climate action begun in 2010, the cuts required per year to meet the projected emissions levels for 2°C and 1.5°C would only have been 0.7 per cent and 3.3 per cent per year on average. However, since this did not happen, the required cuts in emissions are now 2.7 per cent per year from 2020 for the 2°C goal and 7.6 per cent per year on average for the 1.5°C goal. Evidently, greater cuts will be required the longer that action is delayed.

- Further delaying the reductions needed to meet the goals would imply future emission reductions and removal of CO_2 from the atmosphere at such a magnitude that it would result in a serious deviation from current available pathways. This, together with necessary adaptation actions, risks seriously damaging the global economy and undermining food security and biodiversity.

6. Enhanced action by G20 members will be essential for the global mitigation effort.

- This report has a particular focus on the G20 members, reflecting on their importance for global mitigation efforts. Chapter 4 in particular focuses on progress and opportunities for enhancing mitigation ambition of seven selected G20 members – Argentina, Brazil, China, the EU, India, Japan and the United States of America – which represented around 56 per cent of global GHG emissions in 2017. The chapter, which was pre-released for the Climate Action Summit, presents a detailed assessment of action or inaction in key sectors, demonstrating that even though there are a few frontrunners, the general picture is rather bleak.

- In 2009, the G20 members adopted a decision to gradually phase out fossil-fuel subsidies, though no country has committed to fully phasing these out by a specific year as yet.

- Although many countries, including most G20 members, have committed to net zero deforestation targets in the last few decades, these commitments are often not supported by action on the ground.

- Based on the assessment of mitigation potential in the seven previously mentioned countries, a number of areas have been identified for urgent and impactful action (see table ES.2). The purpose of the recommendations is to show potential, stimulate engagement and facilitate political discussion of what is required to implement the necessary action. Each country will be responsible for designing their own policies and actions.

7. Decarbonizing the global economy will require fundamental structural changes, which should be designed to bring multiple co-benefits for humanity and planetary support systems.

- If the multiple co-benefits associated with closing the emissions gap are fully realized, the required transition will contribute in an essential way to achieving the United Nations 2030 Agenda with its 17 Sustainable Development Goals (SDGs).

- Climate protection and adaptation investments will become a precondition for peace and stability, and will require unprecedented efforts to transform societies, economies, infrastructures and governance institutions. At the same time, deep and rapid decarbonization processes imply fundamental structural changes are needed within economic sectors, firms, labour markets and trade patterns.

- By necessity, this will see profound change in how energy, food and other material-intensive services are demanded and provided by governments, businesses and markets. These systems of provision are entwined with the preferences, actions and demands of people as consumers, citizens and communities. Deep-rooted shifts in values, norms, consumer culture and world views are inescapably part of the great sustainability transformation.

- Legitimacy for decarbonization therefore requires massive social mobilization and investments in social cohesion to avoid exclusion and resistance to change. Just and timely transitions towards sustainability need to be developed, taking into account the interests and rights of people vulnerable to the impacts of climate change, of people and regions where decarbonization requires structural adjustments, and of future generations.

- Fortunately, deep transformation to close the emissions gap between trends based on current

Table ES.2. Selected current opportunities to enhance ambition in seven G20 members in line with ambitious climate actions and targets

Argentina

- Refrain from extracting new, alternative fossil-fuel resources
- Reallocate fossil-fuel subsidies to support distributed renewable electricity-generation
- Shift towards widespread use of public transport in large metropolitan areas
- Redirect subsidies granted to companies for the extraction of alternative fossil fuels to building-sector measures

Brazil

- Commit to the full decarbonization of the energy supply by 2050
- Develop a national strategy for ambitious electric vehicle (EV) uptake aimed at complementing biofuels and at 100-per cent CO_2-free new vehicles
- Promote the 'urban agenda' by increasing the use of public transport and other low-carbon alternatives

China

- Ban all new coal-fired power plants
- Continue governmental support for renewables, taking into account cost reductions, and accelerate development towards a 100 per cent carbon-free electricity system
- Further support the shift towards public modes of transport
- Support the uptake of electric mobility, aiming for 100 per cent CO_2-free new vehicles
- Promote near-zero emission building development and integrate it into Government planning

European Union

- Adopt an EU regulation to refrain from investment in fossil-fuel infrastructure, including new natural gas pipelines
- Define a clear endpoint for the EU emissions trading system (ETS) in the form of a cap that must lead to zero emissions
- Adjust the framework and policies to enable 100 per cent carbon-free electricity supply by between 2040 and 2050
- Step up efforts to phase out coal-fired plants
- Define a strategy for zero-emission industrial processes
- Reform the EU ETS to more effectively reduce emissions in industrial applications
- Ban the sale of internal combustion engine cars and buses and/or set targets to move towards 100 per cent of new car and bus sales being zero-carbon vehicles in the coming decades
- Shift towards increased use of public transport in line with the most ambitious Member States
- Increase the renovation rate for intensive retrofits of existing buildings

India

- Plan the transition from coal-fired power plants
- Develop an economy-wide green industrialization strategy towards zero-emission technologies
- Expand mass public transit systems
- Develop domestic electric vehicle targets working towards 100 per cent new sales of zero-emission cars

Japan

- Develop a strategic energy plan that includes halting the construction of new freely emitting coal-fired power plants, as well as a phase-out schedule of existing plants and a 100 per cent carbon-free electricity supply
- Increase the current level of carbon pricing with high priority given to the energy and building sector
- Develop a plan to phase out the use of fossil fuels through promoting passenger cars that use electricity from renewable energy
- Implement a road map as part of efforts towards net-zero energy buildings and net-zero energy houses

USA

- Introduce regulations on power plants, clean energy standards and carbon pricing to achieve an electricity supply that is 100 per cent carbon-free
- Implement carbon pricing on industrial emissions
- Strengthen vehicle and fuel economy standards to be in line with zero emissions for new cars in 2030
- Implement clean building standards so that all new buildings are 100 per cent electrified by 2030

policies and achieving the Paris Agreement can be designed to bring multiple co-benefits for humanity and planetary support systems. These range, for example, from reducing air pollution, improving human health, establishing sustainable energy systems and industrial production processes, making consumption and services more efficient and sufficient, employing less-intensive agricultural practices and mitigating biodiversity loss to liveable cities.

- This year's report explores six entry points for progressing towards closing the emissions gap through transformational change in the following areas: (a) air pollution, air quality, health; (b) urbanization; (c) governance, education, employment; (d) digitalization; (e) energy- and material-efficient services for raising living standards; and (f) land use, food security, bioenergy. Building on this overview, a more detailed discussion of transitions in the energy sector is presented in chapter 6.

8. Renewables and energy efficiency, in combination with electrification of end uses, are key to a successful energy transition and to driving down energy-related CO_2 emissions.

- The necessary transition of the global energy sector will require significant investments compared with a business-as-usual scenario. Climate policies that are consistent with the 1.5°C goal will require upscaling energy system supply-side investments to between US$1.6 trillion and US$3.8 trillion per year globally on average over the 2020–2050 time frame, depending on how rapid energy efficiency and conservation efforts can be ramped up.

- Given the important role that energy and especially the electricity sector will have to play in any low-carbon transformation, chapter 6 examines five transition options, taking into account their relevance for a wide range of countries, clear co-benefit opportunities and potential to deliver significant emissions reductions. Each of the following transitions correspond to a particular policy rationale or motivation, which is discussed in more detail in the chapter:

  - Expanding Renewable Energy for electrification.
  - Phasing out coal for rapid decarbonization of the energy system.
  - Decarbonizing transport with a focus on electric mobility.
  - Decarbonizing energy-intensive industry.
  - Avoiding future emissions while improving energy access.

- Implementing such major transitions in a number of areas will require increased interdependency between energy and other infrastructure sectors, where changes in one sector can impact another. Similarly, there will be a strong need to connect demand and supply-side policies and include wider synergies and co-benefits, such as job losses and creation, rehabilitation of ecosystem services, avoidance of resettlements and reduced health and environmental costs as a result of reduced emissions. The same applies for decarbonizing transport, where there will be a need for complementarity and coordination of policies, driven by technological, environmental and land-use pressures. Policies will need to be harmonized wherever possible to take advantage of interdependencies and prevent undesirable outcomes such as CO_2 leakage from one sector to another.

- Any transition at this scale is likely to be extremely challenging and will meet a number of economic, political and technical barriers and challenges. However, many drivers of climate action have changed in the last years, with several options for ambitious climate action becoming less costly, more numerous and better understood. First, technological and economic developments present opportunities to decarbonize the economy, especially the energy sector, at a cost that is lower than ever. Second, the synergies between climate action and economic growth and development objectives, including options for addressing distributional impacts, are better understood. Finally, policy momentum across various levels of government, as well as a surge in climate action commitments by non-state actors, are creating opportunities for countries to engage in real transitions.

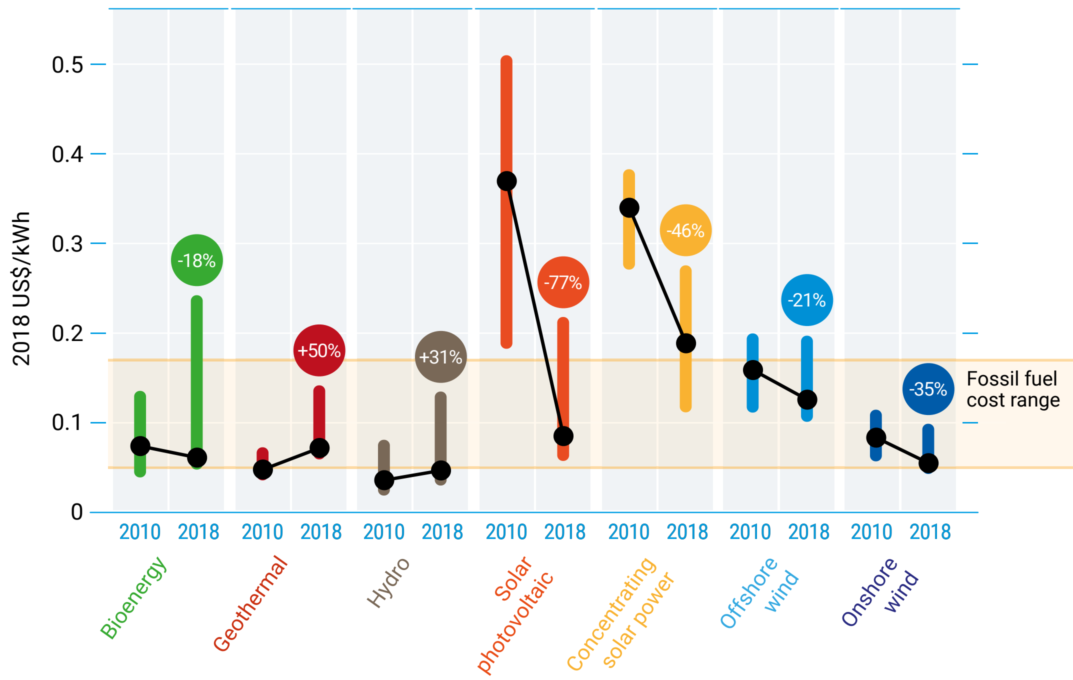
- A key example of technological and economic trends is the cost of renewable energy, which is declining more rapidly than was predicted just a few years ago (see figure ES.5). Renewables are currently the cheapest source of new power generation in most of the world, with the global weighted average purchase or auction price for new utility-scale solar power photovoltaic systems and utility-scale onshore wind turbines projected to compete with the marginal operating cost of existing coal plants by 2020. These trends are increasingly manifesting in a decline in new coal plant construction, including the cancellation of planned plants, as well as the early retirement of existing plants. Moreover, real-life cost declines are outpacing projections.

A short summary of the main aspects of each transition is presented in table ES.3.

Table ES.3. Summary of five energy transition options

Option	Major components	Instruments	Co-benefits	Annual GHG emissions reduction potential of renewables, electrification, energy efficiency and other measures by 2050
Renewable energy electricity expansion	• Plan for large shares of variable renewable energy • Electricity becomes the main energy source by 2050, supplying at least 50 per cent of total final energy consumption (TFEC) • Share of renewable energy in electricity up to 85 per cent by 2050 • Transition	• Flexibility measures to take on larger shares of variable renewable energy • Support for deployment of distributed energy • Innovative measures: cost reflective tariff structures, targeted subsidies, reverse auctions, net metering	• Greater efficiency in end-use energy demand • Health benefits • Energy access and security • Employment	• Power sector: 8.1 $GtCO_2$ • Building sector: 2.1 $GtCO_2$ • District heat and others: 1.9 $GtCO_2$
Coal phase-out	• Plan and implement phase-out of coal • Coal to renewable energy transition • Expand carbon capture usage and storage systems • Improve system-wide efficiency	• Regional support programmes • Tax breaks, subsidies • Carbon pricing • Moratorium policies • De-risking of clean energy investments • Relocation of coal workers (mines and power plants)	• Lower health hazards (air, water, land pollution) • Future skills and job creation	Share of the power emissions reduction from a coal phase-out: 4 $GtCO_2$ (range: 3.6– 4.4 $GtCO_2$), with 1 $GtCO_2$ from the OECD and 3 $GtCO_2$ from the rest of the world
Decarbonize transport	• Reduce energy for transport • Electrify transport • Fuels substitution (bioenergy, hydrogen) • Modal shift	• Pathways for non-motorized transport • Standards for vehicle emissions • Establishing of charging stations • Eliminating of fossil-fuel subsidies • Investments in public transport	• Increased public health from more physical activity, less air pollution • Energy security • Reduced fuel spending • Less congestion	Electrification of transport: 6.1 $GtCO_2$
Decarbonize industry	• Demand reduction (circular economy, modal shifts and logistics) • Electrify heat processes • Improve energy efficiency • Direct use of biomass/ biofuels	• Carbon pricing • Standards and regulations, especially on materials demand reduction	• Energy security • Savings and competitiveness	• Industry: 4.8 $GtCO_2$
Avoid future emissions and energy access	• Link energy access with emission reductions for 3.5 billion energy-poor people	• Fit and auctions • Standards and regulations • Targeted subsidies • Support for entrepreneurs	• Better access • Meet basic needs and SDGs	• N/A

Figure ES.5. Changes in global levelized cost of energy for key renewable energy technologies, 2010-2018



9. Demand-side material efficiency offers substantial GHG mitigation opportunities that are complementary to those obtained through an energy system transformation.

- While demand-side material efficiency widens the spectrum of emission mitigation strategies, it has largely been overlooked in climate policymaking until now and will be important for the cross-sectoral transitions.

- In 2015, the production of materials caused GHG emissions of approximately 11.5 $GtCO_2e$, up from 5 $GtCO_2e$ in 1995. The largest contribution stems from bulk materials production, such as iron and steel, cement, lime and plaster, other minerals mostly used as construction products, as well as plastics and rubber. Two thirds of the materials are used to make capital goods, with buildings and vehicles among the most important. While the production of materials consumed in industrialized countries remained within the range of 2–3 $GtCO_2e$, in the 1995–2015 period, those of developing and emerging economies have largely been behind the growth. In this context, it is important to keep in mind the discussion about the point of production and points of consumption (see figure ES.6).

- Material efficiency and substitution strategies affect not only energy demand and emissions during material production, but also potentially the operational energy use of the material products. Analysis of such strategies therefore requires a systems or life cycle perspective. Several investigations of material efficiency have focused on strategies that have little impact on operations, meaning that trade-offs and synergies have been ignored. Many energy efficiency strategies have implications for the materials used, such as increased insulation demand for buildings or a shift to more energy-intensive materials in the lightweighting of vehicles. While these additional, material-related emissions are well understood from technology studies, they are often not fully captured in the integrated assessment models that produce scenario results, such as those discussed in this report.

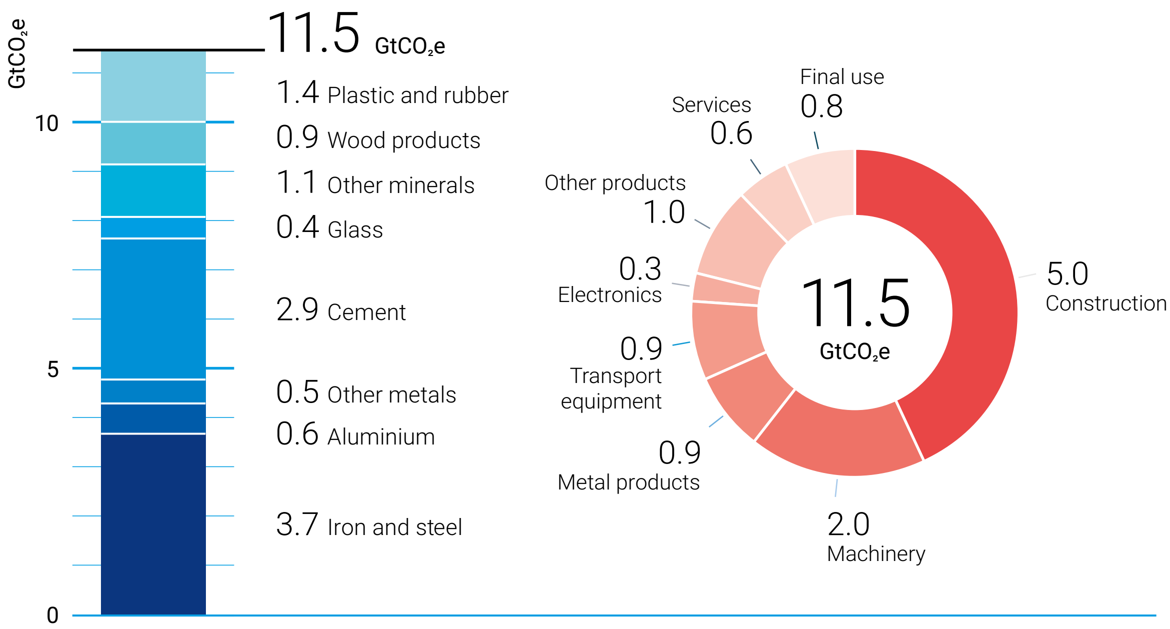
- In chapter 7, the mitigation potential from demand-side material efficiency improvements is discussed in the context of the following categories of action:

  - Product lightweighting and substitution of high-carbon materials with low-carbon materials to reduce material-related GHG emissions associated with product production, as well as operational energy consumption of vehicles.

  - Improvements in the yield of material production and product manufacture.

  - More intensive use, longer life, component reuse, remanufacturing and repair as strategies to obtain more service from material-based products.

Figure ES.6. GHG emissions in $GtCO_2e$ associated with materials production by material (left) and by the first use of materials in subsequent production processes or final consumption (right)



- Enhanced recycling so that secondary materials reduce the need to produce more emission-intensive primary materials.

► These categories are elaborated for housing and cars, showing that increased material efficiency can reduce annual emissions from the construction and operations of buildings and the manufacturing and use of passenger vehicles, thus contributing a couple of gigatons of carbon dioxide equivalent in emission reductions to the global mitigation effort by 2030.

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EXHIBIT E-7

BioScience

American Institute of Biological Sciences

Article Navigation

Issue Section: Viewpoint

World Scientists' Warning of a Climate Emergency FREE

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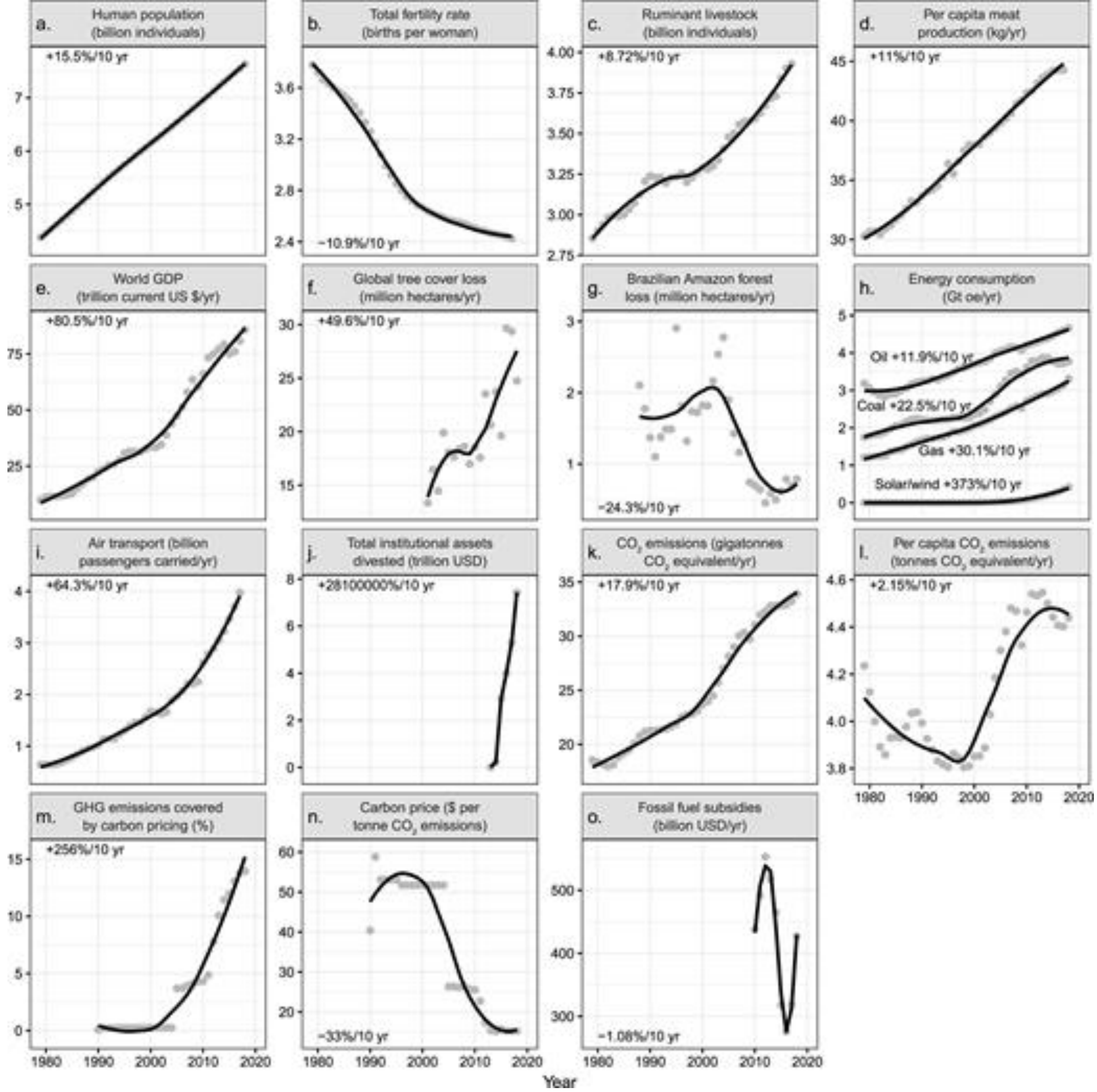
Issue Section: Viewpoint

Scientists have a moral obligation to clearly warn humanity of any catastrophic threat and to "tell it like it is." On the basis of this obligation and the graphical indicators presented below, we declare, with more than 11,000 scientist signatories from around the world, clearly and unequivocally that planet Earth is facing a climate emergency.

Exactly 40 years ago, scientists from 50 nations met at the First World Climate Conference (in Geneva 1979) and agreed that alarming trends for climate change made it urgently necessary to act. Since then, similar alarms have been made through the 1992 Rio Summit, the 1997 Kyoto Protocol, and the 2015 Paris Agreement, as well as scores of other global assemblies and scientists' explicit warnings of insufficient progress (Ripple et al. 2017). Yet greenhouse gas (GHG) emissions are still rapidly rising, with increasingly damaging effects on the Earth's climate. An immense increase of scale in endeavors to conserve our biosphere is needed to avoid untold suffering due to the climate crisis (IPCC 2018).

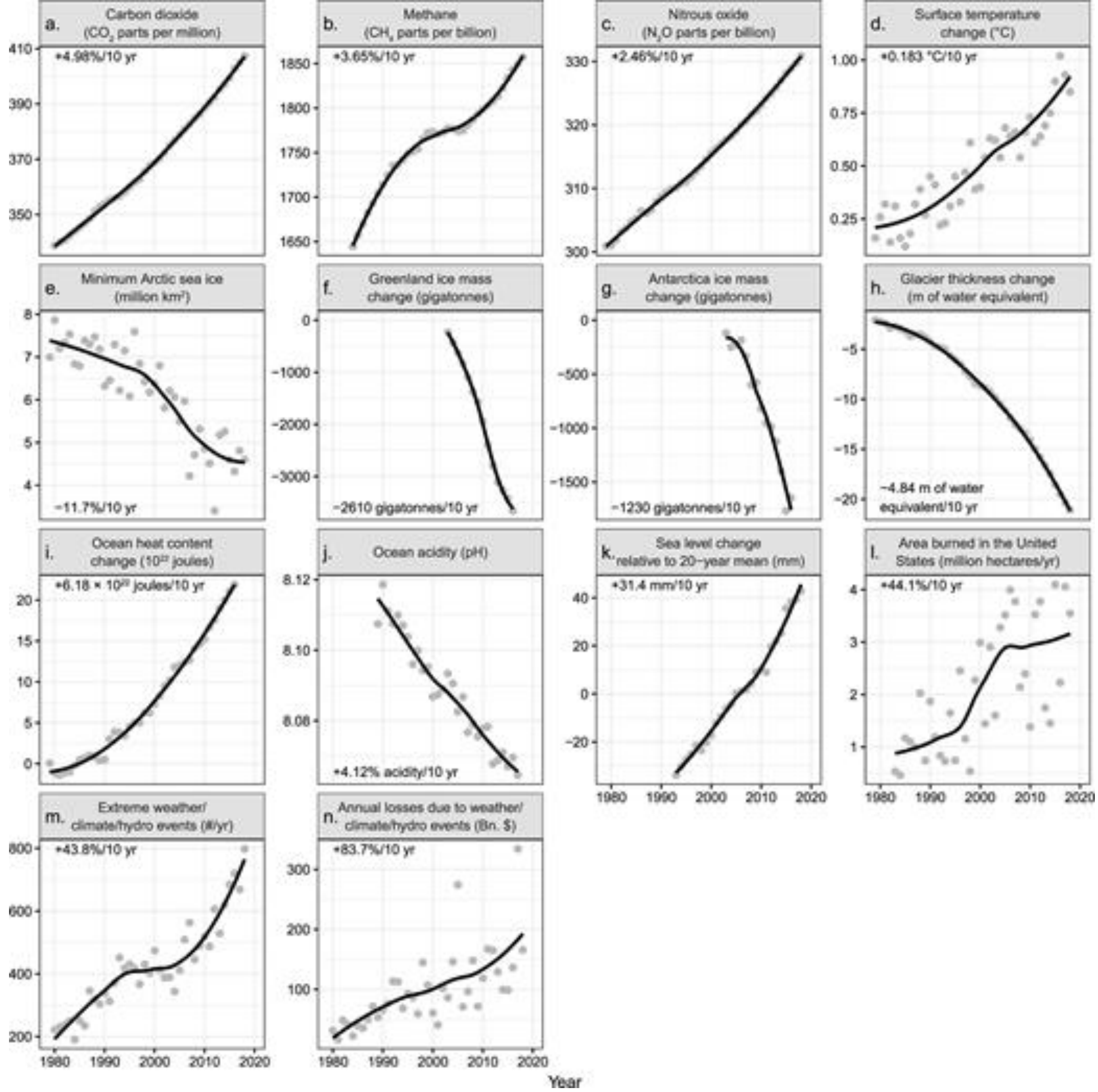
Most public discussions on climate change are based on global surface temperature only, an inadequate measure to capture the breadth of human activities and the real dangers stemming from a warming planet (Briggs et al. 2015). Policymakers and the public now urgently need access to a set of indicators that convey the effects of human activities on GHG emissions and the consequent impacts on climate, our environment, and society. Building on prior work (see supplemental file S2), we present a suite of graphical vital signs of climate change over the last 40 years for human activities that can affect GHG emissions and change the climate (figure 1), as well as actual climatic impacts (figure 2). We use only relevant data sets that are clear, understandable, systematically collected for at least the last 5 years, and updated at least annually.

Figure 1.



Change in global human activities from 1979 to the present. These indicators are linked at least in part to climate change. In panel (f), annual tree cover loss may be for any reason (e.g., wildfire, harvest within tree plantations, or conversion of forests to agricultural land). Forest gain is not involved in the calculation of tree cover loss. In panel (h), hydroelectricity and nuclear energy are shown in figure S2. The rates shown in panels are the percentage changes per decade across the entire range of the time series. The annual data are shown using gray points. The black lines are local regression smooth trend lines. Abbreviation: Gt oe per year, gigatonnes of oil equivalent per year. Sources and additional details about each variable are provided in supplemental file S2, including table S2.

Figure 2.



Climatic response time series from 1979 to the present. The rates shown in the panels are the decadal change rates for the entire ranges of the time series. These rates are in percentage terms, except for the interval variables (d, f, g, h, i, k), where additive changes are reported instead. For ocean acidity (pH), the percentage rate is based on the change in hydrogen ion activity, a_{H+} (where lower pH values represent greater acidity). The annual data are shown using gray points. The black lines are local regression smooth trend lines. Sources and additional details about each variable are provided in supplemental file S2, including table S3.

The climate crisis is closely linked to excessive consumption of the wealthy lifestyle. The most affluent countries are mainly responsible for the historical GHG emissions and generally have the greatest per capita emissions (table S1). In the present article, we show general patterns, mostly at the global scale, because there are many climate efforts that involve individual regions and countries. Our vital signs are designed to be useful to the public, policymakers, the business community, and those working to implement the Paris climate agreement, the

United Nations' Sustainable Development Goals, and the Aichi Biodiversity Targets.

Profoundly troubling signs from human activities include sustained increases in both human and ruminant livestock populations, per capita meat production, world gross domestic product, global tree cover loss, fossil fuel consumption, the number of air passengers carried, carbon dioxide (CO_2) emissions, and per capita CO_2 emissions since 2000 (figure 1, supplemental file S2). Encouraging signs include decreases in global fertility (birth) rates (figure 1b), decelerated forest loss in the Brazilian Amazon (figure 1g), increases in the consumption of solar and wind power (figure 1h), institutional fossil fuel divestment of more than US$7 trillion (figure 1j), and the proportion of GHG emissions covered by carbon pricing (figure 1m). However, the decline in human fertility rates has substantially slowed during the last 20 years (figure 1b), and the pace of forest loss in Brazil's Amazon has now started to increase again (figure 1g). Consumption of solar and wind energy has increased 373% per decade, but in 2018, it was still 28 times smaller than fossil fuel consumption (combined gas, coal, oil; figure 1h). As of 2018, approximately 14.0% of global GHG emissions were covered by carbon pricing (figure 1m), but the global emissions-weighted average price per tonne of carbon dioxide was only around US$15.25 (figure 1n). A much higher carbon fee price is needed (IPCC 2018, section 2.5.2.1). Annual fossil fuel subsidies to energy companies have been fluctuating, and because of a recent spike, they were greater than US$400 billion in 2018 (figure 1o).

Especially disturbing are concurrent trends in the vital signs of climatic impacts (figure 2, supplemental file S2). Three abundant atmospheric GHGs (CO_2, methane, and nitrous oxide) continue to increase (see figure S1 for ominous 2019 spike in CO_2), as does global surface temperature (figure 2a–2d). Globally, ice has been rapidly disappearing, evidenced by declining trends in minimum summer Arctic sea ice, Greenland and Antarctic ice sheets, and glacier thickness worldwide (figure 2e–2h). Ocean heat content, ocean acidity, sea level, area burned in the United States, and extreme weather and associated damage costs have all been trending upward (figure 2i–2n). Climate change is predicted to greatly affect marine, freshwater, and terrestrial life, from plankton and corals to fishes and forests (IPCC 2018, 2019). These issues highlight the urgent need for action.

Despite 40 years of global climate negotiations, with few exceptions, we have generally conducted business as usual and have largely failed to address this predicament (figure 1). The climate crisis has arrived and is accelerating faster than most scientists expected (figure 2, IPCC 2018). It is more severe than anticipated, threatening natural ecosystems and the fate of humanity (IPCC 2019). Especially worrisome are potential irreversible climate tipping points and nature's reinforcing feedbacks (atmospheric, marine, and terrestrial) that could lead to a catastrophic “hothouse Earth,” well beyond the control of humans (Steffen et al. 2018). These climate chain reactions could cause significant disruptions to ecosystems, society, and economies, potentially making large areas of Earth uninhabitable.

To secure a sustainable future, we must change how we live, in ways that improve the vital signs summarized by our graphs. Economic and population growth are among the most important drivers of increases in CO_2 emissions from fossil fuel combustion (Pachauri et al. 2014, Bongaarts and O’Neill 2018); therefore, we need bold and drastic transformations regarding economic and population policies. We suggest six critical and interrelated steps (in no particular order) that governments, businesses, and the rest of humanity can take to lessen the worst effects of climate change. These are important steps but are not the only actions needed or possible (Pachauri et al. 2014, IPCC 2018, 2019).

Energy

The world must quickly implement massive energy efficiency and conservation practices and must replace fossil fuels with low-carbon renewables (figure 1h) and other cleaner sources of energy if safe for people and the environment (figure S2). We should leave remaining stocks of fossil fuels in the ground (see the timelines in IPCC 2018) and should carefully pursue effective negative emissions using technology such as carbon extraction from the source and capture from the air and especially by enhancing natural systems (see “Nature” section). Wealthier countries need to support poorer nations in transitioning away from fossil fuels. We must swiftly eliminate subsidies for fossil fuels (figure 1o) and use effective and fair policies for steadily escalating carbon prices to restrain their use.

Short-lived pollutants

We need to promptly reduce the emissions of short-lived climate pollutants, including methane (figure 2b), black carbon (soot), and hydrofluorocarbons (HFCs). Doing this could slow climate feedback loops and potentially reduce the short-term warming trend by more than 50% over the next few decades while saving millions of lives and increasing crop yields due to reduced air pollution (Shindell et al. 2017). The 2016 Kigali amendment to phase down HFCs is welcomed.

Nature

We must protect and restore Earth's ecosystems. Phytoplankton, coral reefs, forests, savannas, grasslands, wetlands, peatlands, soils, mangroves, and sea grasses contribute greatly to sequestration of atmospheric CO_2. Marine and terrestrial plants, animals, and microorganisms play significant roles in carbon and nutrient cycling and storage. We need to quickly curtail habitat and biodiversity loss (figure 1f–1g), protecting the remaining primary and intact forests, especially those with high carbon stores and other forests with the capacity to rapidly sequester carbon (proforestation), while increasing reforestation and afforestation where appropriate at enormous scales. Although available land may be limiting in places, up to a third of emissions reductions needed by 2030 for the Paris agreement (less than 2°C) could be obtained with these natural climate solutions (Griscom et al. 2017).

Food

Eating mostly plant-based foods while reducing the global consumption of animal products (figure 1c–d), especially ruminant livestock (Ripple et al. 2014), can improve human health and significantly lower GHG emissions (including methane in the "Short-lived pollutants" step). Moreover, this will free up croplands for growing much-needed human plant food instead of livestock feed, while releasing some grazing land to support natural climate solutions (see "Nature" section). Cropping practices such as minimum tillage that increase soil carbon are vitally important. We need to drastically reduce the enormous amount of food waste around the world.

Economy

Excessive extraction of materials and overexploitation of ecosystems, driven by economic growth, must be quickly curtailed to maintain long-term sustainability of the biosphere. We need a carbon-free economy that explicitly addresses human dependence on the biosphere and policies that guide economic decisions accordingly. Our goals need to shift from GDP growth and the pursuit of affluence toward sustaining ecosystems and improving human well-being by prioritizing basic needs and reducing inequality.

Population

Still increasing by roughly 80 million people per year, or more than 200,000 per day (figure 1a–b), the world population must be stabilized—and, ideally, gradually reduced—within a framework that ensures social integrity. There are proven and effective policies that strengthen human rights while lowering fertility rates and lessening the impacts of population growth on GHG emissions and biodiversity loss. These policies make family-planning services available to all people, remove barriers to their access and achieve full gender equity, including primary and secondary education as a global norm for all, especially girls and young women (Bongaarts and O’Neill 2018).

Conclusions

Mitigating and adapting to climate change while honoring the diversity of humans entails major transformations in the ways our global society functions and interacts with natural ecosystems. We are encouraged by a recent surge of concern. Governmental bodies are making climate emergency declarations. Schoolchildren are striking. Ecocide lawsuits are proceeding in the courts. Grassroots citizen movements are demanding change, and many countries, states and provinces, cities, and businesses are responding.

As the Alliance of World Scientists, we stand ready to assist decision-makers in a just transition to a sustainable and equitable future. We urge widespread use of vital signs, which will better allow policymakers, the private sector, and the public to understand the magnitude of this crisis, track progress, and realign priorities for alleviating climate change. The good news is that such transformative change, with social and economic justice for all, promises far greater human well-being than does business as usual. We believe that the prospects will be greatest if decision-makers and all of humanity promptly respond to this warning and declaration of a climate emergency and act to sustain life on planet Earth, our only home.

Contributing reviewers

Franz Baumann, Ferdinando Boero, Doug Boucher, Stephen Briggs, Peter Carter, Rick Cavicchioli, Milton Cole, Eileen Crist, Dominick A. DellaSala, Paul Ehrlich, Iñaki Garcia-De-Cortazar, Daniel Gilfillan, Alison Green, Tom Green, Jillian Gregg, Paul Grogan, John

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Project website

To view the Alliance of World Scientists website or to sign this article, go to https://scientistswarning.forestry.oregonstate.edu.

Supplemental material

A list of the signatories appears in supplemental file S1.

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11,258 scientist signatories from 153 countries (list in supplemental file S1)

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Author notes

William J. Ripple and Christopher Wolf contributed equally to the work.

Supplementary data

biz088_Supplemental_file_S1 - pdf file
biz088_Supplemental_file_S2 - pdf file

Online ISSN 1525-3244

Print ISSN 0006-3568

Mercury contamination in and along the Penobscot River

Map of entire site (documents/site_map_for_webpage_8_8_2016.pdf) (pdf)

Mallinckrodt (Former Holtrachem Site)

The Mallinckrodt facility, formerly known as the HoltraChem Manufacturing Company, sits on 235 acres on the banks of the Penobscot River in Orrington, Maine. The plant operated under several owners from 1967 through 2000. The facility manufactured chlorine, sodium hydroxide (caustic soda), sodium hypochlorite (chlorine bleach), hydrochloric acid and chloropicrin (a pesticide).

(images/2017-8-31.png)

click to enlarge

DEP is currently overseeing cleanup activity at the site to ensure that the requirements of the 2010 BEP Order are met. It is anticipated that the cleanup activities will be complete some time in 2019. For more up to date and detailed information about the site cleanup and expected timelines, visit www.beyondholtrachem.com (http://www.beyondholtrachem.com)

For more information on the history or current status of this site, please contact Chris Swain (mailto:chris.swain@maine.gov) (207) 485-3852

Mallinckrodt data in Google Earth (../../gis/datamaps/brwm_holtrachem/brwm_holtrachem.kmz)

The Penobscot River

In 2000 the Natural Resources Defense Council (NRDC) and the Maine People's Alliance (MPA) filed suit against Holtrachem and Mallinckrodt (Mallinckrodt) in Federal district court alleging that under RCRA 42U.S.C. § 6972(a)(1)(B) Mallinckrodt caused an "imminent and substantial endangerment to health and the environment" as a result of discharging mercury into the Penobscot River. A 2002 judicial opinion and order (http://www.maine.gov/dep/spills/holtrachem/penobriver/orders/GC_07292002_1-00cv069_MePeople_v_Holtrache.pdf) were issued against Mallinckrodt.
Subsequent court orders required the following activities to take place:

- Phase I & II Mercury Study
- Phase III Engineering Study

More detailed information including all court orders, the Phase I and II Mercury Study, and progress on the Phase III Engineering Study are all available at http://www.penobscotmercurystudy.com/ (http://www.penobscotmercurystudy.com/)
Please note: The State of Maine is not a party to this lawsuit or its subsequent court ordered studies. This lawsuit is also separate from the 2010 BEP order currently undergoing implementation (see above).

For further information please contact Susanne Miller (mailto:susanne.miller@maine.gov) , (207) 941-4190

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- Beverage Container Redemption
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Maine's Dioxin Problem

What is Dioxin?

The term "dioxin" describes a group of highly toxic chemicals that are produced by several industrial processes that use or burn products containing chlorine, including incinerators and "kraft" paper mills. Dioxins are among the most potent toxic chemicals known.

What are the effects of dioxins on human health?

There is compelling scientific evidence that dioxins can cause cancer and disrupt hormonal, reproductive, and immune systems in people. The developing fetus and breastfeeding infants are particularly sensitive to the harmful effects of dioxins. Studies suggest that dioxins are also an "endocrine disrupter" – one of a number of toxic chemicals that interfere with our hormone systems by mimicking natural hormones and blocking or disrupting their normal action.

Human Health Hazards Linked to Dioxins

- Cancer
- Birth and Developmental Defects
- Learning Disabilities
- Increased Risk of Diabetes
- Tumor Promotion
- Decreased Fertility
- Reduced Sperm Counts
- Endometriosis
- Suppressed Immune Systems

The U.S. Environmental Protection Agency has found increasing evidence that levels of dioxins in our bodies are at or near the levels at which many, if not all, of these effects may occur. Therefore, the levels at which many, if not all, of these effects may occur. Therefore, any additional dioxins in the environment are a significant concern and must be eliminated wherever possible.

Are certain people at greater risk?

While dioxins are a general public health hazard, they pose even greater dangers to certain groups:

- Developing fetuses and infants
- Developing fetuses and nursing infants have a higher risk because dioxins are passed to them in utero and through their mother's breast milk at the most sensitive stages of their development. Dioxins accumulate to greater amounts in fatty substances, such as breast milk, than in vegetables and fruits.

- Fish consumers
- Certain populations that consume large amounts of fish, such as recreational and avid anglers, subsistence fish consumers and Native Americans are at an increased risk due to their larger consumption

of fish contaminated with dioxins.

Are dioxins a hazard for wildlife?

Yes. Animals on the top of the food chain, such as birds and mammals that eat contaminated fish, face the greatest risks. Last summer, the U.S. Fish and Wildlife Service (USF&W) linked dioxin discharges from the bleach kraft mill in Lincoln with the reproductive failure among Penobscot River bald eagles. Reproduction among eagles nesting within roughly two miles of the Lincoln mill has been as low as 40% below the statewide average. USF&W also examined total dioxin contamination of bald eagle blood and eggs, and found levels in unhatched eggs near the Penobscot River exceeded "safe" levels by up to 85 times.

How does dioxin get into people and wildlife?

Dioxin get into the bodies of people and wildlife primarily through food.

Air
Dioxins generated by burning of certain plastics and other chlorine-containing materials from incinerators and other sources travel through the air and can fall out on our farmland and food crops. Cows and other animals eat the grasses and plants on which the dioxins have fallen, which contaminates their milk and meat.

Water
Dioxins enter the water food chain – aquatic insects, fish, and shellfish – indirectly from "fall-out" from air and directly from the wastewater discharge pollution from certain industries. In Maine, the discharge of dioxins by "bleach kraft" paper mills contaminates fish in papermaking rivers and the tomalley of lobsters in the bays of these rivers to levels that make them unsafe to eat.

Although there are a number of sources of dioxins in our environment, bleach kraft paper mills are the most significant source of dioxin contamination in Maine's waters. Therefore, elimination of dioxin discharges from these mills is not only a priority but also essential to allow people to enjoy the full economic, recreational, and

environmental benefits of our largest waterbodies.

What is the extent of Maine's paper mill dioxin problem?

In 1985, more than 30 years ago, dioxins were first found in fish below Maine's seven "bleach kraft" paper mills that use chlorine compounds to bleach their paper. These seven mills discharge more than 100 million gallons of wastewater a day to the Penobscot, Kennebec, Androscoggin, Presumpscot and St. Croix Rivers. Although the levels of dioxins in mill wastewaters are sometimes undetectable by conventional methods, they are nonetheless enough to contaminate the fish and shellfish because fish act like sponges for dioxins, accumulating them at 25,000-50,000 times the concentrations present in their environment.

Today, women of childbearing age are still warned strictly limit their intake of fish caught from 250 miles of Maine's rivers below paper mills and NO tomalley from lobsters caught along the entire coast. And the general public is advised to severely restrict their consumption of dioxin-contaminated fish and tomalley.

Can Maine's paper mill dioxin problem be solved?

Yes! Papermaking technologies are available and in use today in the United States and worldwide that would eliminate dioxin discharges by using non-chlorine bleaching processes. These processes pave the way to "closed loop" mills that will not discharge any bleaching wastewaters, thereby drastically reducing the discharge of other toxics, turbidity, color, odor, foam, and oxygen-depleting materials. Totally chlorine-free (TCF) papermaking process produces products that are of a brightness and quality comparable to products bleached with chlorine.

Didn't Maine paper mills already commit to eliminate their dioxin discharges?

On April 8, 1996, Governor Angus King announced that the state's seven bleach kraft pulp and paper mills had signed on to the goal of eliminating the discharge of dioxins. Since then, the paper industry has consistently argued that their pledge to "eliminate" dioxins does not mean that their contribution of dioxins to Maine's waters will be zero.

Will conversion to 100% chlorine dioxide (ECF) technologies eliminate the dioxin problem?

No. Maine mills are claiming that a switch from elemental chlorine to chlorine dioxide will "solve" the dioxin problem. However, the chemistry of the ECF process clearly shows that the main bleaching agent, chlorine dioxide, is still capable of producing dioxins. Research by both the pulp industry and the EPA demonstrates that chlorine dioxide bleaching does not ensure total elimination of dioxins. Totally chlorine free bleaching processes will do the job.

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Aquacultural Engineering
Volume 71, March 2016, Pages 1-12

Comparative economic performance and carbon footprint of two farming models for producing Atlantic salmon (*Salmo salar*): Land-based closed containment system in freshwater and open net pen in seawater

Yajie Liu [a], Trond W. Rosten [a], Kristian Henriksen [a], Erik Skontorp Hognes [a], Steve Summerfelt [b], Brian Vinci [b]

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Highlights

- Cost of production for land-based closed containment water recirculating salmon farming systems is approximately the same as the cost of production for traditional open net pen salmon farming systems at this scale, when excluding interest and depreciation.

- Return on investment for traditional open net pen salmon farming at this scale is twice that of land-based closed containment water recirculating salmon farming, when land-based produced salmon are sold at a price premium.

- Carbon footprint of salmon produced in land-based closed containment water recirculating aquaculture systems delivered to market in the US is less than half of that for salmon produced in traditional open net pen systems in Norway that is delivered to the US by air freight.

Abstract

Ocean net pen production of Atlantic salmon is approaching 2 million metric tons (MT) annually and has proven to be cost- and energy-efficient. Recently, with technology improvements, freshwater aquaculture of Atlantic salmon from eggs to harvestable size of 4–5 kg in land-based closed containment (LBCC) water recirculating aquaculture systems (RAS) has been demonstrated as a viable production technology. Land-based, closed containment water recirculating aquaculture systems technology offers the ability to fully control the rearing environment and provides flexibility in locating a production facility close to the market and on sites where cost of land and power are competitive. This flexibility offers distinct advantages over Atlantic salmon produced in open net pen systems, which is dependent on access to suitable coastal waters and a relatively long transport distance to supply the US market. Consequently, in this paper we present an analysis of the investment needed, the production cost, the profitability and the carbon footprint of producing 3300 MT of head-on gutted (HOG) Atlantic salmon from eggs to US market (wholesale) using two different production systems—LBCC-RAS technology and open net pen (ONP) technology using enterprise budget analysis and carbon footprint with the LCA method. In our analysis we compare the traditional open net pen production system in Norway and a model freshwater LBCC-RAS facility in the US. The model ONP is small compared to the most ONP systems in Norway, but the LBCC-RAS is large compared to any existing LBCC-RAS for Atlantic salmon. The results need to be interpreted with this in mind. Results of the financial analysis indicate that the total production costs for two systems are relatively similar, with LBCC-RAS only 10% higher than the ONP system on a head-on gutted basis (5.60 US$/kg versus 5.08 US$/kg, respectively). Without interest and depreciation, the two production systems have an almost equal operating cost (4.30 US$/kg for ONP versus 4.37 US$/kg for LBCC-RAS). Capital costs of the two systems are not similar for the same 3300 MT of head-on gutted salmon. The capital cost of the LBCC-RAS model system is approximately 54,000,000 US$ and the capital cost of the ONP system is approximately 30,000,000 US$, a difference of 80%. However, the LBCC-RAS model system selling salmon at a 30% price premium is comparatively as profitable as the ONP model system (profit margin of 18% versus 24%, respectively), even though its 15-year net present value is negative and its return on investment is lower than ONP system (9% versus 18%, respectively). The results of the carbon footprint analysis confirmed that production of feed is the dominating climate aspect for both production methods, but also showed that energy source and transport methods are important. It was shown that fresh salmon produced in LBCC-RAS systems close to a US market that use an average US electricity mix have a much lower carbon footprint than fresh salmon produced in Norway in ONP systems shipped to the same market by airfreight, 7.41 versus 15.22 kg CO_2eq/kg salmon HOG, respectively. When comparing the carbon footprint of production-only, the LBCC-RAS-produced salmon has a carbon footprint that is double that of the ONP-produced salmon, 7.01 versus 3.39 kg CO_2eq/kg salmon live-weight, respectively.

Previous Next

Abbreviations

CO_2, carbon dioxide; CO_2eq, carbon dioxide equivalents; EBIT, earnings before interest and taxes; FCR, feed conversion ratio; HOG, head-on gutted; IRR, internal rate of return; LBCC, land-based closed containment; LCA, life cycle assessment; NPV, net present value; ONP, open net pen; RAS, water recirculating aquaculture system; ROR, required rate of return; S0, 1/2-year old smolt; S1, 1-year old smolt; TGC, thermal growth coefficent; tkm, ton × kilometers; WFE, whole fish equivalent

Keywords

Salmon; Economics; Carbon footprint; Recirculating aquaculture systems; Net pen aquaculture

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1. Introduction

Farmed Atlantic salmon (*Salmo salar*) is sold globally in various forms and markets. The US is an important market for farmed Atlantic salmon, estimated to be more than 350,000 MT in 2014 (Marine Harvest ASA, 2014), and has shown steady growth since the late 1980s (USDA ERS, 2015). In 2014 the US market was primarily supplied by salmon produced in Chile (126,820 MT), Canada (47,454 MT) and Norway (26,208 MT) (USDA ERS, 2015). The US production of Atlantic salmon (18,000 MT [2012]) is relatively small in comparison to the amount consumed in the US (NOAA, 2013). Limited access to suitable coastal water areas and rigorous regulations in the US (NOAA, 2013) curtail the opportunity to produce Atlantic salmon in open net pen systems, the industry's preferred and established technology for the on-growing phase of salmon farming in Norway, Canada, and Chile. An alternative technology to open net pen systems for salmon production is land-based, closed containment (LBCC) water recirculating aquaculture systems (RAS) technology (LBCC-RAS). LBCC-RAS technology had been used for production of a limited number of species, like eel, beginning in the 1980s (Heinsbroek and Kamstra, 1990). Developments in LBCC-RAS technology since the 1980s have led to the ability to culture a wide variety of fish species including cold-water salmonids (e.g., Arctic char, rainbow trout, and Atlantic salmon to smolt size) (Summerfelt et al., 2004, Bergheim et al., 2009, Dalsgaard et al., 2013, Kolarevic et al., 2014). Most recently, freshwater aquaculture of Atlantic salmon from eggs to harvestable size of 4–5 kg in a LBCC-RAS facility has been demonstrated as a viable production technology (Summerfelt et al., 2013). Land-based, closed containment water recirculating aquaculture systems technology offers the ability to fully control the rearing environment, exclude parasites and obligate pathogens, and provide flexibility in locating a production facility close to the market and on sites where the cost of land and power are competitive. This control and flexibility offers advantages over Atlantic salmon produced in open net pen systems (ONP), which is negatively impacted by sea lice and dependent on access to suitable coastal waters and a relatively long transport distance to supply the US market. Interest in production of Atlantic salmon using LBCC-RAS technology has led to construction of a number of commercial LBCC-RAS farms (Summerfelt and Christianson, 2014). Although their current supply to the US Atlantic salmon market is just beginning, plans for a number of US-based LBCC-RAS farms for Atlantic salmon have been reported in the trade press. It is therefore of particular interest to compare such different approaches for production of the same seafood to the same market.

The aquaculture production of Atlantic salmon has been estimated to exceed 1,900,000 MT in 2014; global production has increased 428% since 1994 (Marine Harvest ASA, 2014). Open net pen farming in the ocean has been the major technology for the on-growing portion of the production cycle. The technology for ONP farming with large net pen volumes, exceeding 60,000 m^3 in one pen, has proven to be cost- and energy-efficient (Ziegler et al., 2013), leading to commercial success and founding a large global business. However, the growth of the industry has not been without environmental conflicts, especially towards wild Atlantic salmon and Sea Trout (*Salmo Trutta*) where negative impacts on wild populations due to escapees have been suggested (Naylor et al., 2005). Alternative methods for growing salmon in closed containment systems for the whole production cycle have been attempted since the beginning of the 1990s, with no commercial success, either land-based or in floating bags (Liu and Sumaila, 2007). Recently, a new interest for producing Atlantic salmon in closed containment systems has arisen (Summerfelt and Christiansen, 2014). A variety of closed containment systems are being suggested (Rosten et al., 2013), but LBCC-RAS technology seems to have found a particular global interest, with LBCC-RAS farms being planned, built and put into production in Europe, North America, China, and Norway (Summerfelt and Christianson, 2014).

Norwegian-farmed Atlantic salmon is sold as fresh, frozen, filleted, smoked and cured product. Fresh whole salmon is the primary product and accounts for approximately three quarters of the total value of exports (Statistics Norway, 2015). Fresh salmon has the highest export price. Denmark, France and Japan are the biggest export countries, making up of one-third of total Norwegian salmon exports (Statistics Norway, 2015). Norwegian salmon made up approximately 8% of the US salmon market in 2014 (USDA ERS, 2015).

The production cost of Atlantic salmon farming in Norway has been charted annually since 1986. From 2008–2012 the production cost has varied between 21.04 and 22.98 NOK per kilo WFE (Directorate of Fisheries, 2014). It has recently increased due to the high cost of sea lice treatment (Liu and Bjelland, 2014). The relatively low investment cost for open net pen production sites compared to the investment cost for proposed LBCC-RAS farms has historically favored open net pen production. Norway has the lowest production cost per kilo of salmon compared to Canada, Great Britain and Chile due to economies of scale (Marine Harvest ASA, 2014).

The economic viability of intensive LBCC-RAS has been evaluated (Muir, 1981, Gempesaw et al., 1993, Losordo and Westerman, 1994, De Ionno et al., 2006, Timmons and Ebeling, 2010), though these studies have largely focused on specific system designs for a single level of output, and have not identified the capital and operating cost savings which may exist as water treatment processes are optimized and as technologies are scaled appropriately. De Ionno et al. (2006) reported that increasing LBCC-RAS facility capacity, increasing sale price, and decreasing facility capital cost were the most important factors affecting economic viability. These savings can be significant and can contribute to the success or failure of an aquaculture business employing this type of technology.

Environmental assessments of ONP salmon production and distribution have identified feed production as a dominating climate aspect of salmon aquaculture production, closely followed by transportation of the salmon to retailer (Ziegler et al., 2013). A shift into more closed systems includes changes such as: replacing ocean current energy with electricity; more alternative materials in the production facilities; controlling interactions with the surrounding environment; collecting and utilizing nutrients in the biosolids produced by the fish; and placing the production close to the market or independent of oceans. There are several potential environmental tradeoffs in this shift. Feed efficiency is especially important, but also the balance between an increase in energy use in the growout phase versus a reduction in transport distance.

This paper aims to investigate whether domestic US production of Atlantic salmon in a LBCC-RAS farm is competitive when compared to a similarly sized ONP system overseas, using investor relevant keys like return of investment, production cost, market price, and carbon footprint. In this paper we present an analysis of the investment needed, the production cost, the profitability and carbon footprint of Atlantic salmon farming from eggs to US market (wholesale) using two different production systems—LBCC-RAS technology and ONP technology using enterprise budget analysis and calculating the carbon footprint with the LCA method. In our analysis we compare the traditional ONP production system in Norway and a model freshwater LBCC-RAS facility in the US. We model the necessary product prices to obtain profitability with LBCC-RAS, and compare the profitability to a similarly-scaled ONP system and provide a sensitivity analysis for the most important impact factors. In addition, we incorporate a comparison of the carbon footprint of the two systems using an overview of the consumed materials, feed, energy, transport and energy source.

2. Materials and methods

The feasibility of two commercial-scale farming systems for Atlantic salmon, a LBCC-RAS farm in the US and an ONP farm in Norway, is evaluated through a concept-level design and capital and operational cost analysis for 3300 MT head-on gutted (HOG) production systems. The economic performance is evaluated in detail using an enterprise budget analysis, while the environmental performance is evaluated in detail using attributional life cycle analysis. The ONP system evaluated here was scaled down from the more common large-sized facilities in Norway to fit to the comparable LBCC-RAS system.

2.1. Open net pen system model

Technical design of the ONP model farm is based upon a biological production plan (i.e., bioplan), data and operational practices obtained from Norwegian salmon farmers. Data and specifications of components are gathered from aquaculture industry suppliers in Norway. The ONP model farm includes concept-level design of floating rings, nets, mooring systems, boats, feed barge systems, camera systems, feed distribution systems and remote power systems. The bioplan, which predicted fish growth and size from smolt to harvestable size, results in two active growout sites, using limitations for fish density of 25 kg/m^3 and maximum allowable biomass of 200,000 fish per unit.

The bioplan for the 3300 MT ONP model farm is based upon average ambient sea temperatures from mid-Norway, stocking with two smolt cohorts per year. The ONP system is assumed to stock a cohort of S1 smolts, average size 100 g, on April 1 and a cohort of S0 smolts, average size 75 g, on August 1. Fish growth and associated feed demand are determined by using specific growth rates (SGR) and feed conversion ratios (FCR) given in feed supplier feeding tables for various fish sizes. Fish growth estimates are reduced by 12% to compensate for handling and treatment of the fish during the production cycle. The overall FCR was set to 1.27 to obtain the average FCR from the last 10 years in Norway (Directorate of Fisheries, 2014). Mortalities for smolt to harvest are set to obtain 16% per generation mortality to comply with a dataset available from mid-Norway (Mattilsynet, 2011).

2.2. Land-based closed containment recirculating aquaculture system model

Technical design of the LBCC-RAS model farm is based on data developed by The Conservation Fund's Freshwater Institute growout trials of Atlantic salmon, some of which has been reported (Summerfelt et al., 2013). This includes concept-level water recirculation system designs for each fish grouping developed in the bioplan. Each water recirculation system design includes multiple recirculation modules to allow for staging and movement of fish throughout the facility. Concept designs for incubation, fry, smolt, pre-growout, and growout rearing areas, as well as a final purging system, are completed using steady-state mass balance analyses. Design water quality criteria used in the mass balance analyses are based on The Conservation Fund's Freshwater Institute growout trials. Thermal growth coefficients (TGC) are used to predict fish growth for the bioplan for the 3300 MT LBCC-RAS model farm. Thermal growth coefficient values are based on data collected in growout trial data from The Conservation Fund's Freshwater Institute. Additionally FCR, mortality, head-on gutted yield, and other performance indicators, which are used to develop a biological plan are taken from past growout trials (Summerfelt et al., 2013). The FCR (kg/kg) and TGC (1000 $g^{1/3}$/ °C days) are set to vary according to these growout trial data at different life stages; FCR: Fry, 0.75; smolt, 0.90; pre-growout, 1.0; growout 1.1; and TGC: Fry, 1.25; smolt, 1.40; pre-growout, 2.00; growout, 2.30. The overall average FCR based on the individual values is 1.09. A maximum biomass density of 80 kg/m^3 is used for the biological plan of the LBCC-RAS model farm.

The steady-state feed requirement for the LBCC-RAS model farm is 11,815 kg/day. Water supply required for the entire 3300 MT LBCC-RAS model farm is based on allowing no more than 75 mg/L nitrate-nitrogen at maximum loading in each recirculation system, assuming no passive denitrification within the systems. The amount of water supply needed to maintain this nitrate-nitrogen level in the recirculation systems is calculated to be 7.7 m^3/min, including 1.1 m^3/min for finishing/purging the harvested salmon before slaughter. The resulting water required per feed fed is 803 L/kg feed for the systems that have feeding fish, i.e., all RAS except the purge system. The power requirement for the model farm is 2458 kW, comprised primarily of power required for the water recirculation pumps (2079 kW); the total power required per unit of live weight salmon produced is 5.4 kWh/kg (4.6 kWh/kg for pumping only).

Concept-level design characteristics for each rearing area in both production systems are summarized in Table 1; the inputs required for the two systems are summarized in Table 2; illustrative renderings are shown in Fig. 1. The technical design for each model farm allowed the progression of capital and operating costs for comparison of the two production systems. Cost data used in the development of the concept-level estimates provided here is a combination of industry standard published cost data (Directorate of Fisheries, 2014, Marine Harvest ASA, 2014, RS Means, 2010) and project specific vendor quotations obtained in 2010–2011.

Table 1. Concept-level design characteristics for each rearing system in a 3,300 MT HOG Atlantic salmon land-based closed containment farm (LBCC-RAS) and a 3300 MT HOG open net pen farm (ONP).

Fish Rearing Area	Modules	Units per module	Unit diameter by depth (m × m)	Total Rearing Volume (m^3)	Module Flow Rate (m^3/min)	Total Flow Rate (m^3/min)	Total Makeup Flow Rate (m^3/min)	Maximum Module Feed Rate (kg/day)
LBCC-RAS—fry	1	18	2 by 1.0	57	1.5	1.5	0.08	22.9
LBCC-RAS—smolt	2	4	9 by 2.0	1,018	11.4	22.7	0.19	248.0
LBCC-RAS—pre-growout	3	4	10 by 3.0	2,827	22	66	0.57	549.5
LBCC-RAS—growout	8	5	16 by 4.25	34,180	95	757	5.75	2063.5
LBCC-RAS—final purging	1	2	16 by 4.25	1,709	38	38	1.1	–

ONP—System[a]	2	6	157 by 40	587,000	–[b]	–[b]	–[b]	–

a

The ONP system is a growout system from smolts to harvestable size. Smolts and harvest/packing of the salmon are modeled to be provided by subcontractors.

b

The water exchange in the ONP system is dependent upon water current and conditions of the nets (mesh size and fouling).

Table 2. Input factors and assumptions used in the financial analysis of two production models (LBCC-RAS system and ONP system) for a 3300 MT HOG Atlantic salmon farm.

Input factors	ONP system	LBCC-RAS system
Feed (US$/kg)	1.48	1.50
Farm labor (# person)	6	10
Farm labor (US$/person/year)	125,000	45,000
Processing labor (# person)	–	6
Processing labor (US$/person/year)	0.38/kg[a]	37,500
Livestock (US$/smolt or US$/egg) smolt)	1.53	0.30
Electric (US$/kWh)	0.17	0.05
Oxygen (US$/kg)	–	0.20
Wellboat cost (US$/kg[a])	0.92	–
Bicarbonate (US$/kg)	–	0.35
Management (US$/year)	–	500,000
Other operating cost	0.43 US$/kg fish	–
Insurance (US$/kg[a])	0.02	0.02[b]
Tax level	28%	28%

Equity ratio	30%	40%
Interest loans	3.0%	6.0%

a

Whole fish weight.

b

First year is 0.04 US$/kg.

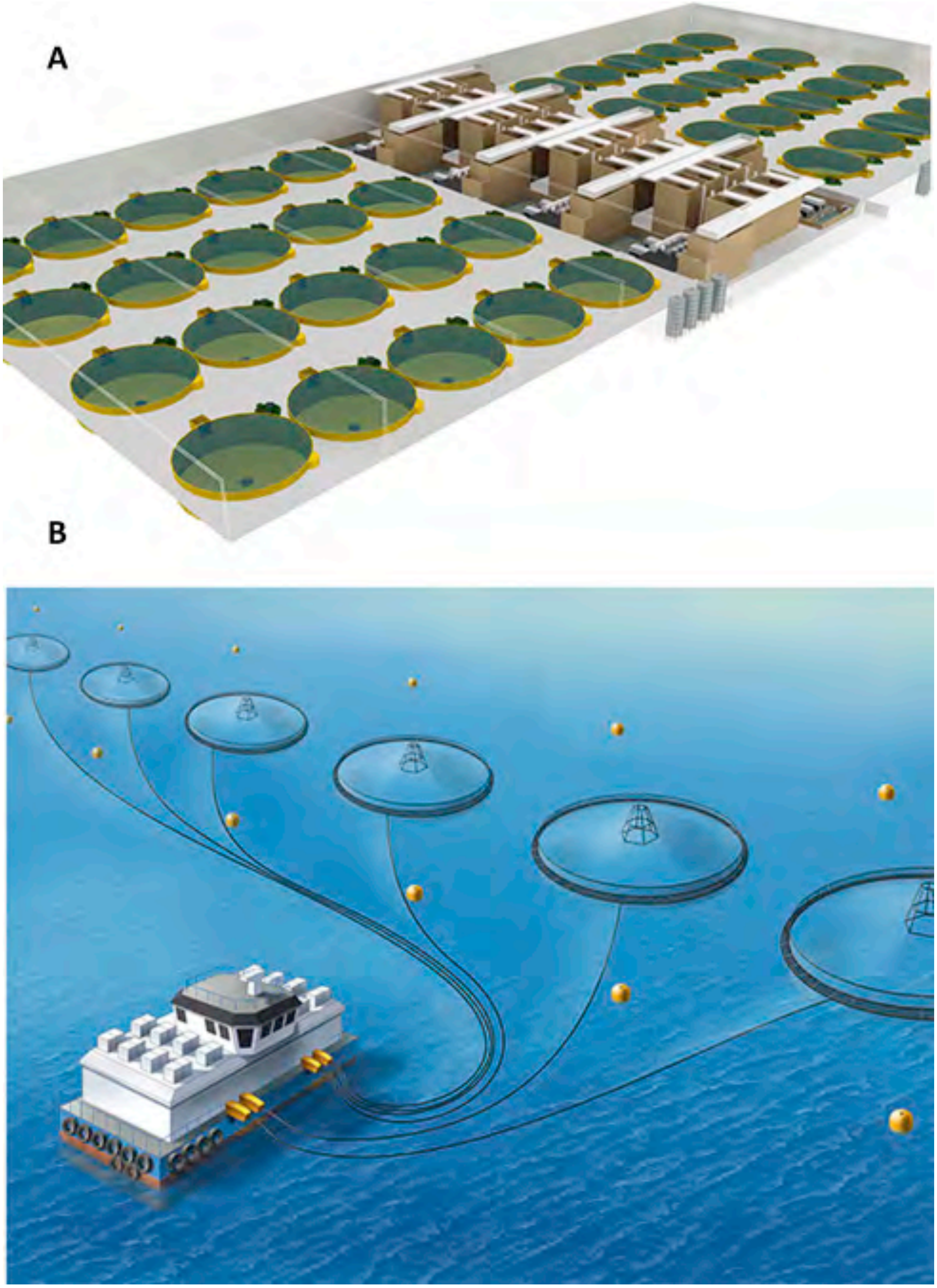

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Fig. 1. Concept-level renderings of the growout rearing area in a 3300 MT HOG Atlantic salmon LBCC-RAS farm (A) and ONP farm (B).

2.3. Economics

Salmon aquaculture is a commercial operation whose purpose to be profitable. The prerequisite for a business to be sustainable is to be profitable in both the short- and long-term and over the investment horizon. The financial performance of these two aquaculture production systems is investigated using an enterprise budget analysis; this allows an assessment of the feasibility and profitability of the two systems. Enterprise budgets, also called production budgets, provide a framework within which all the components of costs and revenues associated with the production of farm products are itemized. The budget is constructed on a production basis, and the assessment is built upon a cash flow analysis. The profitability is calculated based on financial statements such as income statement and balance sheets.

There are a number of well-developed analytical techniques for analyzing profitability (Liu and Sumaila, 2007, Kumar and Engle, 2011). Net present value (NPV) is a commonly used parameter to provide an objective decision of an investment and project. Net present value takes into account the time value of money, and is the difference between the present value of total costs and total revenue over an operational horizon. Positive NPV indicates that an investment is worthwhile. In addition to NPV, other indicators are also used as assessment criteria; these include gross margin, return on investment (ROI), internal rate of return (IRR), payback period, and break-even production and price. Gross margin is expressed as revenue minus variable costs; net income or profit is revenue minus all costs. Return on investment is the rate of return on the initial capital investment and is estimated by profit before taxes divided by the capital investment. Internal rate of return is the discount rate at which net present value of profit is set equal to zero. Breakeven production/price represents the expected production level and market price at which total sale revenue covers total production costs. Breakeven analysis can inform the conditions necessary for the business to become profitable or to remain in business.

2.3.1. Enterprise budget

The enterprise budget is estimated based on a total production of 4000 MT wet weight, which is equivalent to 3300 MT of head-on gutted weight. Head-on gutted yield is estimated to be 88% after a 5% loss of weight during final purging for both the ONP and the LBCC-RAS production systems. The estimates of total investment cost and operating cost of each cost item are based on the production system design models and their associated bioplans. The costs include two parts: capital cost and operating cost.

2.3.2. Capital cost—ONP model

Capital costs incur at the beginning of the operation, and most of these costs are one-time costs. The capital cost for the 3300 MT ONP model farm is based on information gathered from the Norwegian aquaculture industry, and is thereby considered representative for an ONP farm constructed and operated according to Norwegian laws and regulations (Norway, 2008). The ONP model farm includes 3 licenses and 12 pens, and their associated physical components consisting of floating rings, nets, mooring systems, boats, feed barge systems, camera systems, feed distribution systems and remote power systems. The cost of each item is estimated based on current market price suppliers' command. Compared to estimates reported by Marine Harvest (Marine Harvest ASA, 2014), the capital cost for the ONP model farm is considered representative for a two site ONP farm. We assume that the lifespan of nets and feeding system is 5 years, floating rings is 8 years, camera and power systems is 10 years, and the remainder of the equipment is 20 years. These lifespans are used for calculation of depreciation and replacement cost.

The cost for an ONP farming license in Norway is included in the capital cost estimate for the ONP model farm. The current cost of ONP farming licenses is much higher when compared to license costs of the 1990s (Färe et al., 2005); cost for a license in the current open market is approximately 55 million Norwegian kroners, which is equivalent to 8 million US dollars[1] (Aardal, 2014). The total capital cost of the ONP model farm including licenses at current prices is estimated to be 29.7 million US dollars for a total production of 3300 MT head-on gutted salmon (Table 3).

Table 3. Capital expenses for a 3,300 MT HOG LBCC-RAS and ONP Atlantic salmon farm.

ONP system cost components	Cost (US$)
Licences	23,571,429
Floating rings	1,834,286
Nets	857,143
Moorings	342,857
Boats	1,285,714
Feed barges	1,371,429
Camera systems	214,286
Feed distributors	34,114

Power systems	188,571
Total	29,699,829

LBCC-RAS system cost components	**Cost (US$)**
RAS Systems	26,640,557
Effluent treatment	3,487,500
Water supply	675,000
Processing	2,112,030
Building	9,426,413
Engineering	5,080,980
Construction management	1,058,538
Bond	254,049
Contingency (10%)	4,848,102
Total	53,583,169

2.3.3. Capital cost—LBCC-RAS model

The capital cost of the LBCC-RAS model farm includes all RAS systems, water supply, effluent treatment systems, buildings, engineering services, construction management services, a primary processing facility and general contractor bonding requirements. These components are itemized based on material, equipment, labor and subcontractor services, upon which the costs are estimated. Ten percent contingency is applied to capture uncertainty associated with this level of cost estimation. We assume that the lifespan of materials and equipment is 10 years and the lifespan for buildings and tanks is 20 years. These lifespans are used for calculation of depreciation and replacement cost. The cost of bonding is included as insurance may be required by owners that builders must have for large projects and is typically passed back to the owner. There are currently no comparable license costs for a LBCC-RAS farm in the US. The total capital cost including contingency of the LBCC-RAS model farm is estimated to be 53.6 million US dollars for a total production of 3300 MT head-on gutted salmon (Table 3).

2.3.4. Operating cost—ONP model

The operating cost for the ONP model farm is estimated based on data collected by the

Norwegian Directorate of Fisheries (2014) and also Marine Harvest ASA (2014), and are the average costs of the last five years, 2009–2013. Since there are uncertainties associated with these items and the overall cost has increased gradually in the last several years, we applied a 2% increase for the first five year's estimates, and a 3% increase for the remaining year's estimate to account for uncertainties for each cost item. In other words, it is assumed that each cost item will increase 2% for the first five years and 3% for the rest. The operating costs are the average estimates over 15 years. The breakdown of costs is presented in Table 4.

Table 4. Operating expenses for a 3,300 MT HOG LBCC-RAS and ONP Atlantic salmon farm.

Cost item	ONP system		LBCC-RAS system	
	Cost (US$)	Cost (NOK)	Cost (US$)	Cost (NOK)
Feed	2.05	14.34	1.90	13.33
Smolt	0.47	3.30	–	–
Egg	–	–	0.12	0.86
Labor	0.31	2.15	0.52	3.65
Well boat	0.18	1.23	–	–
Health	0.03	0.18	–	–
Electricity	–	–	0.33	2.32
Oxygen	–	–	0.15	1.07
Water treatment	–	–	0.09	0.62
Insurance	0.02	0.16	0.18	1.27
Primary processing	0.43	3.03	0.12	0.83
Transportation	0.25	1.58	–	–
Sales & marketing	0.09	0.60	–	–
Maintenance	0.14	0.99	0.47	3.26
Interest	0.60	4.21	0.65	4.52
Depreciations	0.18	1.28	0.58	4.09

Others	0.33	2.32	0.49	3.45
Total	5.08	35.37	5.60	39.27

2.3.5. Operating cost—LBCC-RAS model

The operating cost for the LBCC-RAS model farm is estimated based on the bioplan designed for an annual production of 3300 MT after primary processing. Cost items include feed, oxygen, bicarbonate, electricity, eggs, labor, stock insurance, interest and depreciation. Feed amount and thus cost, is calculated based on the feed required for growth multiplied by feed conversion ratio at different life stages. The amounts, and thus costs, of oxygen and bicarbonate are dependent on the feed required. Oxygen required is estimated to be 0.60 kg oxygen per kg feed, which includes an oxygen transfer efficiency of 75%. Bicarbonate required is estimated to be 0.20 kg bicarbonate per kg feed, which includes a base chemical availability of 75%. The cost of the electricity is determined by the RAS design, which identified all pumps and motors required for operation. The number, and thus cost, of eggs required is estimated by the assumed mortality rates at different life stages. Labor costs for the LBCC-RAS model farm include management (biological and maintenance), fish culture technicians, laboratory technicians, maintenance mechanics, and primary processing staff. It is assumed that insurance cost for the first year of operation is 4% of standing biomass, and then that declines to 2% of standing biomass in the following years. The ratio between interest and cash for capital cost and first year operating cost was 60/40, and an interest rate of 6% was used. Depreciation of each item was estimated using a straight line approach, meaning depreciation cost was charged evenly throughout the useful life of each capital item. Maintenance cost was estimated to be 10% of the total variable cost. To capture unknown costs, a contingency cost is also included which was assumed to be 10% of the total cost. The increase with 2% for the first 5 years and 3% for the rest are also applied for each cost item due to unforeseen future changes, same as the ONP system.

2.3.6. Sales and income

It takes approximately one year for salmon to grow to market size, therefore, there is no harvest for Year 1 and a proportionally smaller harvest for Year 2. In Year 3 and onwards, a constant harvest of 3300 MT is assumed for the ONP and LBCC-RAS systems. The price used here is the export market price of fresh gutted salmon in the US market, which is approximately 5.97 US$/kg or 41.8 NOK/kg averaged weekly price for the year 2014 (Statistics Norway, 2015). It is also assumed that the price for salmon in the future would increase in a similar way as the cost items, i.e., increased by 2% for the first five years and 3% for the rest. However, preliminary sales of Atlantic salmon produced by a LBCC-RAS farm have commanded a significant price premium (Guy Dean, Albion Fisheries (Vancouver, BC), personal communication, September 4, 2014), here a 30% price premium is assumed which is approximately 7.76 US$/kg. The total sales revenue is calculated based on export price and annual harvest.

2.4. Carbon footprint

The carbon footprint is the sum of potential climate impacts that a product causes from a defined part of its life cycle. The carbon footprint was calculated using life cycle assessment (LCA) methodology that is a tool for environmental assessment (ISO, 2006a, ISO, 2006b). It assesses the inputs of energy and material to the system and from that calculates potential environmental impacts caused by the resource use and outputs to nature in the form of emissions, waste and products. This LCA includes both direct emissions from the feed and salmon production and indirect emissions caused by production and distribution of the commodities and infrastructure that underpin the salmon life cycle.

The potential climate impact, the global warming potential, is calculated by characterizing all emission and impacts into CO_2 equivalents (CO_2eq) according to their radiative properties based on IPCC guidelines (IPCC, 2007).

The goal of the carbon footprint was to compare the potential climate impacts from different ways of providing a retailer in Seattle, WA (US) with Atlantic salmon:

1a) Salmon from a LBCC-RAS system in the US running on electricity generated from a source that uses a typical mix of coal, gas, nuclear, wind and hydropower. Salmon is assumed to be transported fresh to the retailer 250 km by truck.

1b) Salmon from a LBCC-RAS System in the US running on electricity generated from a source that uses 90% hydropower and 10% coal. Salmon is assumed to be transported fresh to the retailer 250 km by truck.

2a) Salmon from a Norwegian ONP system. Salmon is assumed to be transported fresh, first with truck in Norway to Oslo, 520 km, and then with airfreight to Seattle, 7328 km.

2b) Salmon from a Norwegian ONP system. Salmon is assumed to be transported frozen, first with truck in Norway to Oslo, 520 km, and then with ship from Ålesund, Norway, to Seattle through the Panama Canal, 16,473 km.

The functional unit for the assessment, the basis for comparison, was 1 kg of gutted salmon with head on, at the retailer gate. For each case, the assessment included the complete production system, from production of feed ingredients, smolt production and construction of facilities, equipment and transports.

It was assumed that the salmon was gutted close to the production facility and that all byproducts, such as guts, skin and trimmings were utilized mainly for feed production. Mass allocation was applied meaning that the carbon footprint up to slaughter was allocated between the head-on-and-gutted salmon and the byproducts based on their mass. Thus, per unit of mass live salmon and head on and gutted salmon have the same carbon footprint. Important cut offs, processes that are not included in the assessment include: slaughtering process, treatment of the biosolids from the LBCC-RAS system, and transport infrastructure.

2.4.1. Carbon footprint data

Table 5 presents important activity data for the carbon footprint of the two systems. Data for the LBCC-RAS system was derived from the concept-level design. Data for the Norwegian ONP system is gathered from industry actors and industry statistics (Winther et al., 2009, Hognes et al., 2011, Hognes et al., 2014). Data on the climate impacts from capital and operational inputs were modeled with data from the LCA inventory database Ecoinvent v3.1 (2013). Since many of the operations performed at the ONP farm are performed by sub-contractors, and the extent of the activities, e.g., cleaning and priming of nets, are dependent of exact location, these data are based on the assumption of a representative production model.

Table 5. Inventory data for carbon footprint for two production models (LBCC-RAS system and ONP system) for a 3300 MT HOG Atlantic salmon farm. All numbers are per ton of salmon produced or transported.

	Unit	LBCC-RAS System	ONP system
Feed, economic FCR	ton	1.09	1.27
Concrete	kg	82.5	–
Steel, reinforcing	kg	14.40	0.63
Steel, chromium 18/8 steel	kg	–	0.70
Glass fiber	kg	8.93	–
Nylon	kg	–	1.01
Polypropylene	kg	–	1.79

Polyethylene	kg	–	0.28
Fuel	l	–	10.50
Electricity	kWh	5460	–
Oxygen (liquid)	kg	656	–
Lime (calcium carbonate)	kg	219	–
EPS for transport packaging	kg	25	25
Ice	kg	300	300

Both the LBCC-RAS and ONP systems are modeled using the same feed. Based on LCAs of the average Norwegian salmon feed in 2012, the feed is associated with a carbon footprint of 2.5 kg CO_2eq/kg feed at the feed factory gate. This is a feed with the following composition: 12% marine oil; 19% marine protein; 19% oil from crops; 39% protein from crops; 8% starch from crops and 3% micro ingredients (minerals, vitamins, pigments and other). This carbon footprint reflects a feed where 50% of the soy in the feed is equal to the average Brazilian soy, as modeled by the Agrifootprint database (Centre for Design and Society of the RMIT University, 2014), and the remaining coming from old farms where climate impacts from land use change is not included (Hognes et al., 2014).

Electricity for the LBCC-RAS system in case 1b is modeled as being generated from 90% hydropower and 10% coal power with data from Ecoinvent v3.1 (2013). This case is included as an illustrative case for what is possible if this type of electricity is available. Electricity loss of 3.5% was included for the transmission of the power and transformation from high to medium voltage. This associated the electricity with a carbon footprint of 0.04 kg CO_2eq/kWh. For comparison, the Ecoinvent v3.1 database also provides a dataset that describes the electricity available in the regional entity of the North American Electric Reliability Corporation (NERC), that gives a carbon footprint of 0.64 kg CO_2eq/kWh. This was the electricity data used for the LBCC-RAS system in case 1a.

Road transport was modeled with a truck carrying 20 tons of fish, consuming 3.7 L of diesel per 10 km and has a carbon footprint of 0.09 kg CO_2eq/tkm; this also includes fuel used for the refrigeration system and emission of refrigerants (Winther et al., 2009). The fuel consumption reflects a modern truck. For the ONP system in case 2a, airfreight was modeled using data for a Boeing 747–400 from the Agrifootprint database, with an emission factor of 1.18 kg CO_2eq/tkm (Centre for Design and Society of the RMIT University, 2014). This plane is assumed to use 100% of its load capacity (3600 tons) and the emissions include landing and takeoff for a flight of approximately 10,000 km. For the ONP system in case 2b, ship transport was modeled with data for a ship of 120,000 tons (dry weight) utilizing 80% of its capacity, with an emission factor of 0.004 kg CO_2eq/tkm. Emissions from preparing for the return of the ship and re-loading is included in this data. Fuel for running refrigeration systems and emissions of refrigerants were also included with an emission factor of 0.1 kg CO_2eq/h (Winther et al., 2009).

3. Results

3.1. Financial analysis

3.1.1. Capital cost

Tables 3 reports the capital cost of ONP and LBCC-RAS systems. In the ONP system, the largest cost is license fees, which are almost 80% of the total capital cost, while the physical structure cost only accounts for 20%. For LBCC-RAS, the largest cost is the RAS system which is half of the total cost; 18% of the LBCC-RAS capital cost is for building structures. The capital cost of LBCC-RAS is 80% higher than that of the ONP system given the same production capacity. It is important to note that the replacement costs of some cost items are not included in this table, but incorporated into the cash flow analysis.

3.1.2. Operating cost

The operating cost breakdowns for the two systems are presented in Table 4 and Fig. 2. The total operating costs for the two systems are relatively similar, with LBCC-RAS only 10% higher than the ONP system. Without interest and depreciation, the two production systems have an almost equal operating cost, 4.30 US$/kg for ONP and 4.37 US$/kg for LBCC-RAS. Feed is the single biggest cost item accounting for 41% and 34% of the total operating cost for the ONP and the LBCC-RAS systems, respectively. It is worthwhile to note that these operating costs are subject to change with site selection due to differences in power costs, feed shipping costs and other factors. For example, operating costs presented here do not include the cost of heating or cooling that may or may not be required based on the geographic location of the LBCC-RAS facility.

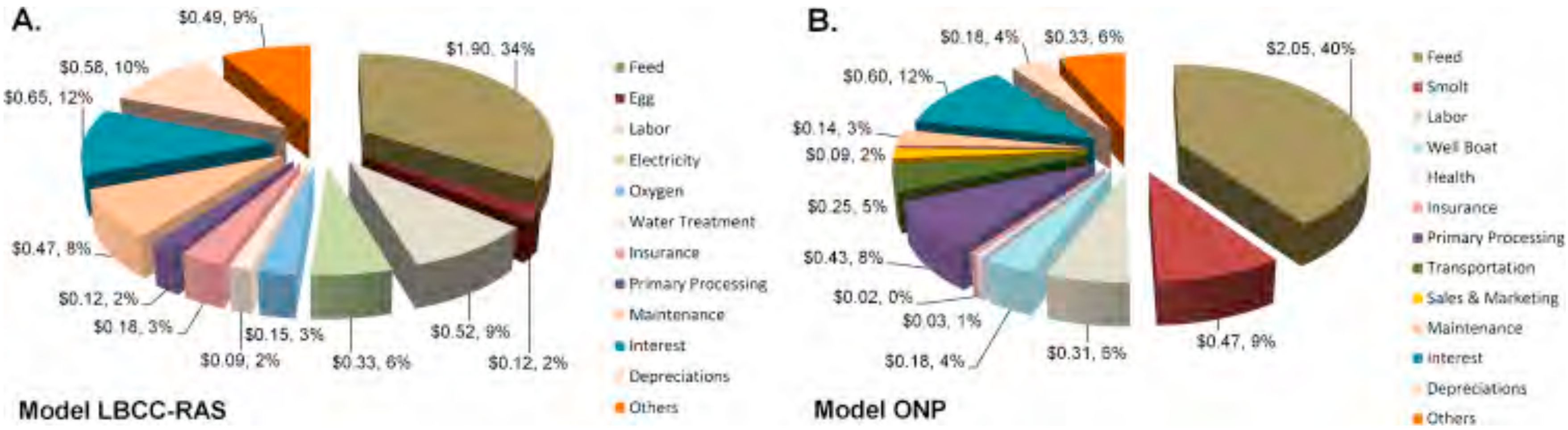

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Fig. 2. Estimated production costs (US$/kg HOG) according to the investments, product price estimates and the biological production plans for a model 3300 MT HOG Atlantic salmon LBCC-RAS farm (A) and ONP farm (B).

3.1.3. Financial indicators

The financial analysis is conducted for a period of 15 years; the discount rate is set to seven percent. The summary of the financial analysis is presented in Table 6. Overall, the ONP model system is financially better than the LBCC-RAS model system, even when the LBCC-RAS is selling product with a price premium. All three cases generate positive operating margins, indicating that from a production operating perspective, all are financially viable. The LBCC-RAS system selling salmon at a price premium is comparatively as profitable as the ONP system, even though its NPV is negative (–20,340,000 US$) and its return on investment (9.01%) is lower than the ONP system's ROI (17.77%). However, when selling salmon at the same price as the ONP system, the LBCC-RAS system is barely financially profitable and not an attractive investment. To be comparable with an ONP system, the LBCC-RAS system must command higher market price to breakeven or be profitable.

Table 6. Economic indicators for a 3,300 MT HOG LBCC-RAS and ONP Atlantic salmon farm. Also presented are indicators for the LBCC-RAS farm selling salmon with a 30% price premium.

Economic indicator	ONP system	LBCC-RAS system	LBCC-RAS system premium price

Operating (gross) margin	38.39%	17.56%	40.64%
Profit margin	23.62%	(–)	18.18%
NPV (million US$)	3.54	–120.20	–20.34
IRR before EBIT	15.96%	(–)	13.28%
IRR	7.94%	(–)	2.67%
ROI	17.77%	(–)	9.01%
Break-even production (MT)	1251	3307	2387
Pay-back period (year)	5.63	(–)	11.10
Break-even price (US$)	5.33	(–)	6.44

The IRR can be considered as the true expected yield from an investment. The IRR before EBIT for the LBCC-RAS with price premium is calculated to be 13.28%. The real IRR for the LBCC-RAS with price premium is 2.67%. The discount rate of 7% used here is below the IRR before EBIT and thus the LBCC-RAS would be an investment that results in a positive NPV. However, the discount rate of 7% used here is also above real IRR, and that investment in LBCC-RAS results in a negative NPV. Investors must make investment decisions based on her expectation(s) on return, whether using the IRR of 13.28% or 2.67%.

3.1.4. Sensitivity analysis

The financial results are very sensitive to some factors. For instance, prices have substantial influence on the results, and are subject to short- and long-term fluctuations due to dynamics in supply and demand. Feed is the largest cost item, so any changes in feed price and feed utilization have large impacts on the economic performance of the operations. Recent figures have suggested the cost of feed has increased gradually. The assumption for feed conversion ratio during growout is one of the most critical values in the estimation because it drives the largest component of the cost of production—feed cost during growout. Performance data from repeated Freshwater Institute trials indicate a feed conversion ratio less than 1.1 during the final growout phase (Summerfelt et al., 2013); utilizing lower FCR values during final growout instead of 1.1 would reduce the cost of production, by potentially up to 6%. Feed is also the major factor influencing the carbon footprint. Other factors such as mortality rates, power cost and mortality also have impacts on financial performance.

3.2. Carbon footprint results

If the alternative is intercontinental export of fresh salmon by air, then a modern and efficient LBCC-RAS system close to the market can be a more climate friendly alternative, even when running on electric power that mainly originates from fossil fuels (7.4 versus 15.2 kg CO_2eq per kg HOG salmon at retailer gate in Seattle). If the LBCC-RAS system is running on 90% hydropower the carbon footprint of the LBCC-RAS salmon is further reduced to 4.1 kg CO_2eq per kg HOG salmon at the retailer gate. The most climate friendly alternative of all is to ship frozen salmon from Norway with a modern container ship, 3.8 kg CO_2eq per kg HOG salmon at the retailer gate. A frozen product is not directly comparable with a fresh, but with modern freezing technologies, the quality of frozen products is not necessarily inferior to fresh.

At the producer gate, before transport to the retailer in Seattle, the production systems have climate impacts per unit produced of 3.4 versus 3.7 and 7.0 kg CO_2eq/kg salmon live-weight for the ONP and the LBCC-RAS using hydropower or average fossil fuel based electricity, respectively (Table 7 and Fig. 3).

Table 7. Estimated carbon footprint with component contributions at the producer gate and the retailer gate for the following scenarios: (1a) Salmon from a LBCC-RAS system in the US running on a typical electricity mix; (1b) Salmon from a LBCC-RAS system in the US running on electricity generated predominantly from hydropower; (2a) Salmon from a Norwegian ONP system transported by airfreight to Seattle; (2b) Salmon from a Norwegian ONP system transported by ship to Seattle.

	1a)	1b)	2a)	2b)
Feed production	2.69	2.69	3.21	3.21
Construction of facility and equipment	0.39	0.39	0.02	0.02
Grow out and smolt (fuel and electricity)	3.48	0.21	0.16	0.16
Oxygen and lime	0.44	0.44	–	–
At producer gate (live weight)	7.01	3.73	3.39	3.39
Transport, road	0.03	0.03	0.06	0.062
Transport, air or water	–	–	11.40	0.09
Packaging and ice	0.37	0.37	0.37	0.11
Refrigeration during transport	0.00	0.00	0.00	0.10

At retailer gate (HOG)	7.41	4.14	15.22	3.75

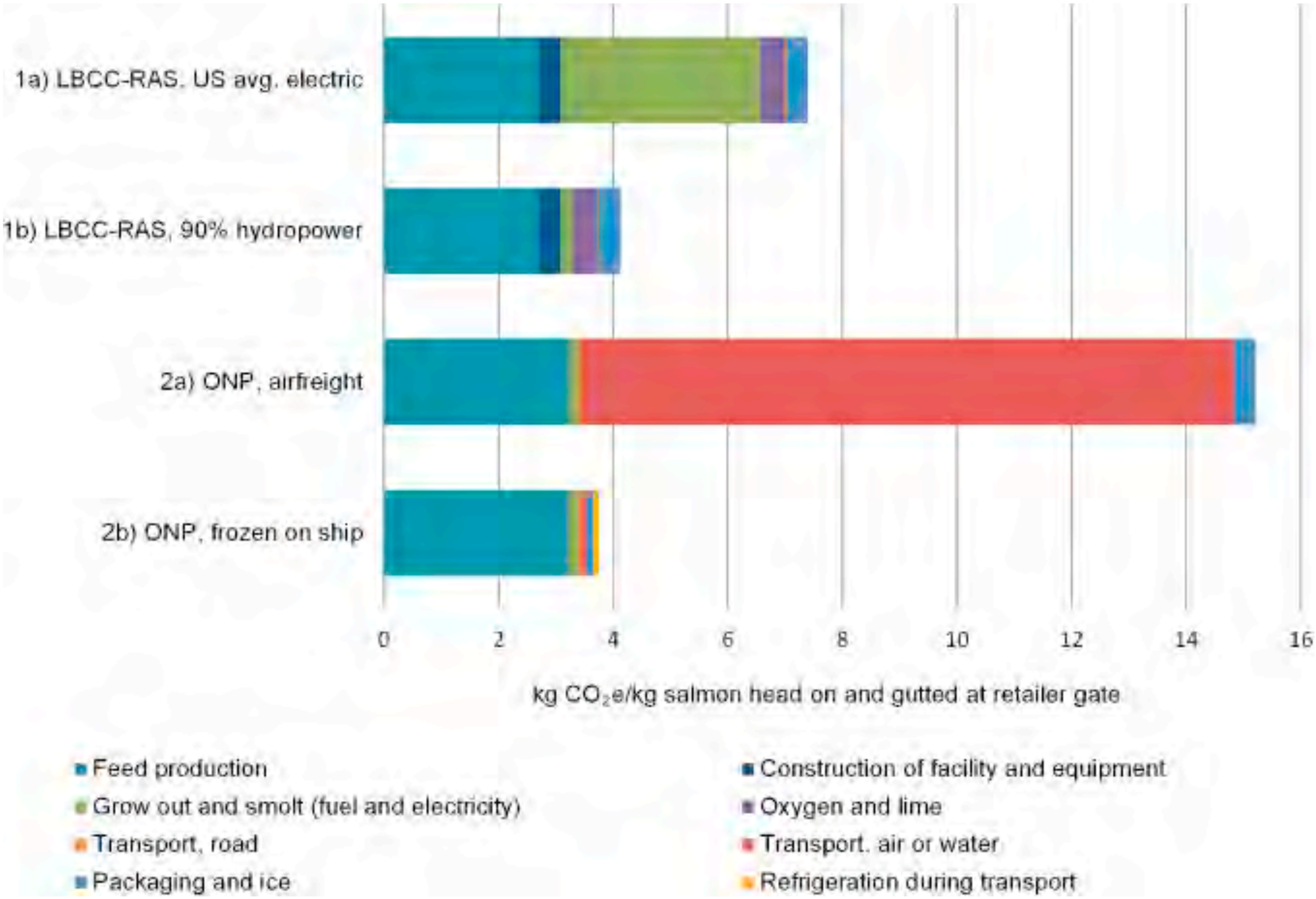

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Fig. 3. Estimated carbon footprint with component contributions at the producer gate and the retailer gate for the following scenarios: (1a) Salmon from a LBCC-RAS system in the US running on a typical electricity mix; (1b) Salmon from a LBCC-RAS system in the US running on electricity generated predominantly from hydropower; (2a) Salmon from a Norwegian ONP system transported by airfreight to Seattle; (2b) Salmon from a Norwegian ONP system transported by ship to Seattle.

The more general findings confirmed what previous LCAs have found that fish feed is the dominant climate aspect for the selected salmon products, but that energy used in growout and emissions from transports are also important. Production and maintenance of equipment and production facilities are not important climate aspects compared to feed production, transport and water treatment.

4. Discussion

Given current technology development and possible increases in market price for salmon and production input factors, the ONP system still remains the most profitable, even at this relatively small scale. To achieve comparative financial performance, the LBCC-RAS system requires a price premium, at least 25% higher than current market prices. This is mainly due to considerably higher capital cost for the LBCC-RAS system. However, the difference in operating costs between both systems is relatively small. If the feed conversion ratio can be further improved from 1.1 to 1.0 for LBCC-RAS systems, the gap will be even smaller since feed is the most important cost item. However, improvements in feed conversion ratio are also likely to happen in ONP systems, so the difference in the future for optimized systems is hard to predict. It is important to note that ONP systems are just for the growout phase in Norway, and that salmon now spend more of their lifecycle in LBCC-RAS smolt production facilities (Dalsgaard et al., 2013). Additionally, other costs such as managing sea lice and loss due to disease could further increase the operating cost of ONP systems significantly (Liu and Bjelland, 2014). The largest limiting factor for using LBCC-RAS system appears to be the capital cost. Thus, there are economic incentives for advancing technological innovations of LBCC-RAS systems that can reduce capital cost to become more competitive with ONP systems.

LBCC-RAS systems are not a new technology, and have been used for the last twenty years for growing out both freshwater species, such as eel and catfish, and marine species like trout and sea bass (Martins et al., 2010, Badiola et al., 2012). There is increasing interest in applying LBCC-RAS for the salmon smolt stage in Nordic countries and Europe (Dalsgaard et al., 2013). However, due to low returns on investment and and a history of failures when the technology was not well advanced, LBCC-RAS have not been used widely.

Economic incentives have been proven to be more effective than traditional command and control policy (Bailly and Willmann, 2001, Liu et al., 2013). Market-based economic instruments such as taxes, subsidies, fees/charges and eco-labeling can create incentives for the industry to foster cost-effective technology innovation and adaptation such as LBCC-RAS systems or other closed containment systems (Rosten et al., 2013). However, such incentive-based approaches have to be executed with the vectors of market and social forces such as environmental policy and consumers. Eco-labeling farmed products would be a market-driving power to change consumers' purchasing behavior. Concerned consumers are likely willing to pay more for the products which are produced in an environmental sustainable way. Subsidies and taxes can be used to stimulate cost-effective technology innovation and adaptation, e.g., rewarding improved environmental performance from capturing and controlling waste streams in closed-containment systems or eliminating sea lice infestation.

While environmental policies may also have a role, in Norway, "green" concessions for salmon farming require the aquaculture industry to employ technological and operational innovations and solutions to reduce the incidence of salmon lice and escapes. These technologies require upfront investment which can be significant, but over the long run, such technological innovation would increase social license to operate through improved environmental performance and reduced conflict with other resource users, perceived market payoffs through reduced costs to obtain and maintain a license to operate, and monitor and mitigate negative impacts, e.g., costs of recapturing escapes. Captured nutrient laden waste streams associated with LBCC-RAS may also result in ancillary revenue streams, e.g., aquaponics.

The carbon footprint analysis showed that, with respect to climate impact, producing close to the market is preferable by a good margin, especially when the LBCC-RAS system utilized electricity generated from 90% hydropower and the alternative is to export fish fresh, fast and a long distance. Even if salmon is LBCC-RAS produced with electricity based on fossil fuels, intercontinental export of fresh fish on airplanes is not a preferable option. However, environmental considerations involving high inputs of electricity should be followed up with a discussion of what is the environmentally optimum way of using available electricity. Electricity is of the highest energy quality available, and many industrial and infrastructure processes do not have an alternative to electricity. Export of frozen salmon was the best option of all, but cannot be directly compared with fresh salmon. Still, this result points to a future option, with product development, improvement of logistic chain management, to maintain quality through the transport, and market acceptance, frozen intercontinental export has the potential to compete with local LBCC-RAS products. Another important assumption regarding transport is that most intercontinental export of fresh Norwegian salmon is done with flights that also carry passengers. Thus a more precise comparison should include details and insight into how it is reasonable to allocate the fuel used and corresponding emissions between goods and passengers. In addition to this, the LCA data that is available on flight transport is highly variable. This indicates that more precision on the exact age/technology and size of the aircrafts being used should be included.

The carbon footprint contained several cut-offs and assumptions that limits the conclusions that can be drawn, e.g., the same data on feed was used for salmon production in the US and Norway. There are likely to be differences in the carbon footprint of the feeds that would actually be used. A potentially important cut off is that treatment of the biosolids was not included. Biosolids could be seen as both waste and a resource, but either way handling it will involve the use of both energy and transports together with emissions from the biosolids itself. Still, this aspect was left out because it would be difficult to compare to the ONP system, where there is no biosolids capture and waste feed and feces is discharged directly in the ocean.

Most often, the concentrated effluent of LBCC-RAS systems now in operation in North America and Europe are treated in order to meet stringent wastewater discharge permits. Thus a flow-through system will have a higher eutrophication potential. However, if the concentrated effluent of a LBCC-RAS is not treated there is no such advantage to be obtained. Rosten et al. (2013) suggests a classification system for closed containment systems from 1 to 4, where category 4 is the most closed system towards the external environment applying treatment of both inlet and outlet of a LBCC-RAS system. Acidification and toxic potentials are strongly connected to energy consumption and thus similar to climate impacts with regards to where and why they occur.

Aquaculture technologies have been compared with LCA previously; our assessment was compared with a selection of peer reviewed literature (Table 8). This selection of literature points to the same main conclusions: feed production is a dominating factor for carbon footprint in salmon aquaculture, and for LBCC-RAS, the use of energy for water treatment can be equally important and equipment and infrastructure is of minor importance. The importance of energy used for water treatment depends on how this energy is produced. The literature also shows that important parameters for the LCA, such as the FCR and energy used for water treatment varies considerably. This study has not gone into the details to explain these differences, but important reasons are probably that the studies rely on different assumptions, experimental data and site specific properties. These differences make it difficult to compare the final carbon footprint among studies. In addition to differences in the aquaculture systems that are compared, it is also not possible to be sure that the data on feed that are used are comparable. Finally, there are also methodical differences, e.g., Ayer and Tyedmers (2009) used allocation based on the energy content in the different outputs rather than their mass and Samuel-Fitwi et al. (2013) used system expansion.

Table 8. Data from published studies on LCAs of LBCC-RAS for rearing salmonids.

System analyzed and method	Electricity consumption (kWh/kg)	Feed efficiency	Carbon footprint of product (kg CO_2eq/kg)	Reference
Salmon production with marine net-pen, marine floating bag, land-based saltwater flow	Net-pen: 1.49	Net-pen: 1.30	Net-pen: 2.07	Ayer and Tyedmers

through and a land-based freshwater RAS. Assessment from feed and smolt production to farm gate	Land, flow through: 13.4 Land, recirculating: 22.6 Electricity mix 80% fossil fuels	Land, flow through: 1.17 Land, recirculating: 1.45	Bag: 1.90 Land, flow through: 2.77 Land, recirculating: 28.20	(2009)
Trout production with a flow through system and a hypothetical recirculating system. From feed production to fish ready for slaughter	Flow through low pumping: 2.36 Recirculation: 10.7 86.6% nuclear energy	Flow through: 1.10 Recirculation: 0.80	Flow through: 2.02 Recirculation: 1.60–2.04	d'Orbcast el et al. (2009)
Rainbow trout production in flow through systems (extensive and intensive) and recirculating system. From feed production to fish ready for slaughter	Intensive flow through: 2.55 Recirculating: 19.6 Electricity based on fossil fuels	Flow through: 0.91–1.2 Recirculating: 0.86	Flow through extensive: 2.24 Flow through intensive: 3.56 Recirculating: 13.60	Samuel-Fitwi et al. (2013)
Rainbow trout production with flow-through, recirculating and semi-closed system. From feed production to fish ready for slaughter	Flow-through: 0.65 Recirculating:	Flow through: 1.15 Recirculating:	Flow through: 1.16 Recirculating:	Dekamin et al. (2015)

	8.1 Semi-closed: 7.6	1.47 Semi-closed: 1.57	6.10 Semi-closed: 6.38	
Salmon production with in a floating tank, flow-through, solid-walled aquaculture system. From feed production to fish ready for slaughter	Actual production cycle: 7.3 Intended production cycle: 4.6	Hatchery: 1.5 Grow out actual: 1.46 Grow out intended 1.37	Actual: 3.87 Intended: 3.03	McGrath et al. (2015)

The conclusion with regards to the hypothesis that a LBCC-RAS produced salmon will have a higher carbon footprint than one from an ONP system is solely dependent on what carbon dioxide emission the electricity production is attributed with and the method and form that the product is transported to market with. If the electricity for the LBCC-RAS is considered to be primarily hydropower then the carbon footprint for the two systems at the producer gate are relatively close (3.39 and 3.73 kg CO_2eq/kg salmon live-weight). If the electricity for the LBCC-RAS is considered to be the average US mix dominated by fossil fuels, then the LBCC-RAS has a higher carbon footprint at the producer gate (7.01 versus 3.39 kg CO_2eq/kg salmon live-weight). The carbon footprint demonstrates the importance of the emissions associated with electricity generation for LBCC-RAS systems.

In a market where electric power is a commodity in short supply, and where power markets are connected through economy and/or the grid, it is challenging to argue that power is supplied from one specific source. On top of this, renewable energy, such as hydropower, is often sold to clients that pay extra for a certificate to claim that their electricity is produced from renewable sources. For this system to work, as well as for carbon footprint, it would require a mechanism that ensures that the sum of certificates that are sold do not exceed the renewable power that is actually available and that everybody who does not buy certificates uses a carbon footprint of their electricity that does not include the renewables that are sold with certificates. This is what is then called the residue mix. As far as these authors know, no such system exists today and it is recognized to be “good practice” to use the average production mix in the grid where the electricity use takes place. The grid here being what is physically and/or economically connected.

Extending the carbon footprint to include transport to market for the most likely production systems, fresh salmon produced in LBCC-RAS systems close to a US market that use an average US electricity mix and fresh salmon produced in Norway in ONP systems shipped to the same market by airfreight, yields the result that LBCC-RAS has a much smaller carbon footprint, 7.41 versus 15.22 CO_2eq/kg salmon HOG, respectively. In this case the carbon footprint associated with transport is the dominant factor for ONP-produced salmon, accounting for more carbon footprint than the entire production on a kg salmon HOG basis (Fig. 3).

5. Conclusions

In this paper, we compare the economic and environmental performance of the Norwegian open net pen system in the sea and the US land-based, closed containment water recirculating aquaculture system for the same production capacity targeting the same US market. The scale used for the open net pen system is smaller than the average operation scale in Norway, so both systems could be scaled up to higher production capacity. This will result in reduction in cost due to scale of economy. However, the main findings are drawn:

- Capital cost for land-based closed containment water recirculating salmon farming systems is significantly greater than capital cost for traditional open net pen salmon farming systems, but increasing net pen site license costs in Norway are bringing the capital costs closer.

- Production cost for land-based closed containment water recirculating salmon farming systems is approximately the same as production cost for traditional open net pen salmon farming systems at this scale, when excluding interest and depreciation.

- Return on investment for traditional open net pen salmon farming at this scale is twice that of land-based closed containment water recirculating salmon farming, when land-based produced salmon are sold at a price premium.

- Internal rate of return for earnings before interest and tax for traditional open net pen salmon farming at this scale is only slightly greater than that of land-based closed containment water recirculating salmon farming, when land-based produced salmon are sold at a price premium.

- The carbon footprint of salmon produced in land-based closed containment water recirculating aquaculture systems that are using a typical US electricity mix based on fossil fuels is twice that of salmon produced in traditional open net pen systems, when delivery to the market is not included.

- The carbon footprint of salmon produced in land-based closed containment water recirculating aquaculture systems delivered to market in the US is less than half of that for salmon produced in traditional open net pen systems in Norway that is delivered to the US by air freight.

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[1] 1 US dollar = 7 Norwegian kroners.