

TECHNICAL ASSESSMENT FOR IMPROVE AQUACULTURE

SECTOR: OCEAN

AGENCY LEVEL: AQUACULTURE PRODUCERS

KEYWORDS: AQUACULTURE, RENEWABLE ENERGY, ENERGY
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*Note: For some of the technical reports, the result section is not yet updated. Kindly refer to the model for the latest results.

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EXECUTIVE SUMMARY

Aquaculture is a fast-growing industry and since 2014, aquaculture has provided more fish for human consumption than capture fisheries. As the aquaculture sector will become an important part of food systems within the next 10 years, it is necessary to address its sustainability and environmental impact. There are many potentials for aquaculture operations improvement to reduce climate impact, with different maturity of implementation. The majority of GHG emissions are coming from feed production, and recently many pressure has been put on feed advancement and reducing its environmental impact. However, due to the lack of market data, feed alternatives are not included as a part of this solution.

Project Drawdown defines *Improve aquaculture* as shifting from diesel and petrol-based generators to hybrid systems that are partly based on renewable energy resources to reduce greenhouse gas emissions from on-site energy use in animal aquaculture. It is assumed that *Improve aquaculture* primarily happens at the farmer and producer level.

The Total Addressable Market is defined in terms of million tons of live weight produced in aquaculture, which is projected to increase from 73 million tons live weight production in 2014 to approximately 126 million tons globally in 2050. The current solution adoption (2014) is set as zero because greenhouse gas emissions account only for diesel and petrol on-site energy systems. Ten scenarios have been built following the predicted growth of global renewable energy supply (PV and wind power) as presented in major reports on energy transformation. These scenarios were combined to produce *Plausible* (average of lowest), *Ambitious* (average of medium), and *Maximum* (average of highest) scenarios.

Total adoption in the *Plausible Scenario* is 38.05 million tons of live weight in 2050, representing 30% percent of the total addressable market. Total adoption in the *Ambitious Scenario* is 60.93 million tons of live weight in 2050, representing 61 percent of the total addressable market. Total adoption in the *Maximum Scenario* is 87.35 million tons of live weight in 2050, representing 69 percent of the total addressable market. Climate impact is 0.50, 0.78, and 1.02 gigatons of carbon-dioxide equivalent reduction in 30 years timeframe in the *Plausible*, *Ambitious* and *Maximum* scenarios respectively.

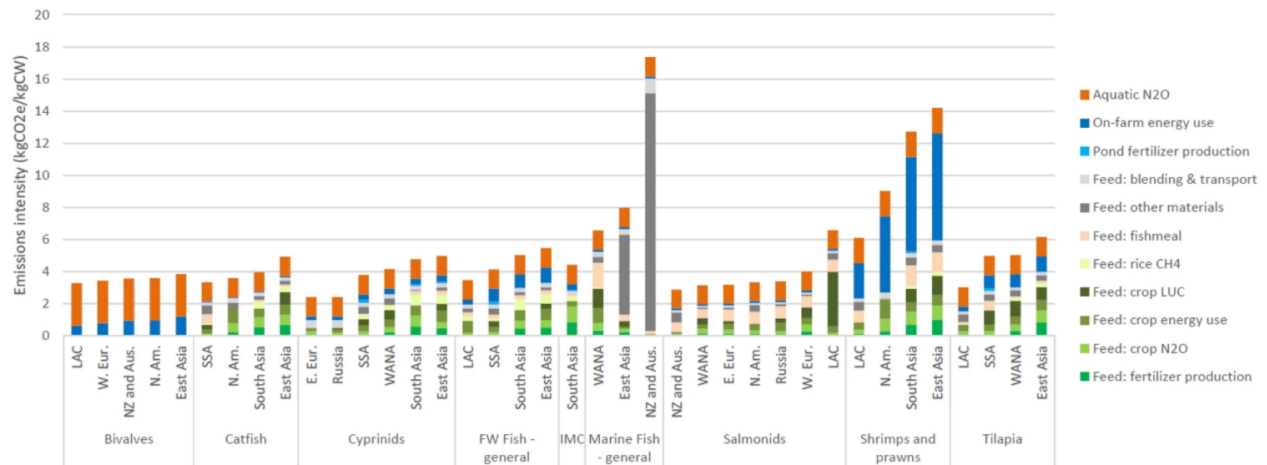
1 LITERATURE REVIEW

1.1 STATE OF THE PRACTICE

Aquaculture is a fast-growing industry mainly because the wild fishery stocks are fully exploited and the wild-caught seafood output remains stagnant. Around 90 percent of assessed fish stocks are either fully

exploited or overexploited, therefore to close the food production gap for future generations, aquaculture has to expand (FAO, 2018). Since 2014, aquaculture has provided more fish for human consumption than capture fisheries, and by 2030, aquaculture is expected to provide about 59 per cent of the fish available for human consumption, representing one of the fastest-growing animal food sectors (FAO, 2018). Because this sector is relatively young and many aquaculture operations are yet to be established, producers have the opportunity to adjust to low carbon emissions principles. In Norway in particular, which is the major producer of salmon, the usage of diesel and petrol in aquaculture will be forbidden beginning in 2021 (Novaton, 2021). Independent companies are also setting targets to cut their greenhouse gas (GHG) emissions e.g. Grieg Seafood has recently put forward a target to cut their total GHG emissions by 35% by 2030 and by 75% by 2050. From a global perspective, the UN Global Compact provided principles for sustainable development of global aquaculture with targets to adopt Science Based Targets Initiative and demonstrate CO₂ emissions reductions by 2030 in alignment with the Paris Agreement and adhere to targets under a 1.5°C temperature increase threshold (UN Global Compact, 2020).

As the aquaculture sector will become an increasingly important part of food systems within the next 10 years, it is necessary to address its sustainability and environmental impact. There are several issues important to address to achieve sustainable growth of the aquaculture industry, such as pollution, land conversion, introduction of non-native species, use of antibiotics, feed, and GHG emissions from aquaculture operations (UN Global Compact, 2020). GHG emissions occur along the whole seafood supply chain with the majority of emissions coming from feed use. The global analysis of GHG emissions from animals aquaculture shows that emissions arising from the production of crop feed materials as well as from fishmeal production, feed blending and transport account for 57% of global aquaculture GHG emissions (MacLeod et al., 2020). The rest of emissions arise from nitrification and denitrification of nitrogenous compounds and on-farm energy use (e.g. pumping water, lighting and vehicles):



Emissions intensity of the main aquaculture groups, 2017. *Source* calculated in this study. *IMC* Indian Major Carps, *E. Eur.* Eastern Europe, *LAC* Latin America and the Caribbean, *N. Am.* North America, *NZ and Aus.* New Zealand and Australia, *SSA* Sub-Saharan Africa, *W. Eur.* Western Europe, *WANA* West Asia and North Africa.

Figure 1.1 Emissions intensity of the main aquaculture groups in 2017 (MacLeod et al., 2020).

Approximately half of the total aquaculture production requires external feed inputs (FAO, 2018). Originally a significant portion of aquafeed consisted of fishmeal and fish oil extracted from small pelagic fish (Turchini et al., 2019). Despite noticeable improvement in economic feed conversion ratios (FCRs, kg of dry feed input per kg of whole fish slaughtered) and decreasing rates of fish meal and oil in feeds over the past two decades, growth in aquaculture production has been rapid enough that demand for fish meal and oil has outpaced supply (Tacon and Metian 2008; Naylor et al. 2009; Shepherd and Jackson 2013) resulted in rising fish meal and oil prices, providing an economic impetus to seek alternatives. Usage of captured fish in aquafeed has been regarded as unsustainable leading to depletion of wild fish stocks (Naylor et al., 2009). Currently, the components of aquafeeds that produce the largest emissions are terrestrial animal-based proteins such as feather or poultry meal (Pelletier et al., 2018). Other components consist of soy that might have lower GHG emissions than terrestrial animal-based components with an exception of Brazilian soy that drive to losses of soil organic carbon as a result of land-use change (deforestation for new soy plantations) (Pelletier et al., 2018; Wijkström, 2009). Because those different feed components (fish, terrestrial animal-based feed and soy-based feed) has limitation and rising costs, the aquafeed industry has already been turning towards feed alternatives in recent decades such as microalgae, other plant-based alternatives, bacterial and insects (Becker, 2007; Pelletier et al., 2018). Some of those alternatives might be an exciting replacement of fish, terrestrial animal and soy-based components as they consist of key amino acids and have high protein content (Henry et al., 2015; Shah et al., 2018), however, there are still limitations to apply those alternative aquafeed components globally (Cottrell et al., 2020). First of all, most of the published studies analyzing alternative aquafeed components in fed aquaculture are experimental

studies that in our opinion are hard to translate into real market growth data. Therefore, the adoption cases would have to be based on possible growth rate not true growth of the market, so not fulfilling the Drawdown modelling requirements. Moreover, the effects of alternative feeds on aquaculture growth and performance is mixed and the environmental impacts are poorly understood (Cottrell et al., 2020). To conclude, alternative feed is not possible to be modelled as a Drawdown solution.

Another opportunity for GHG emissions reduction related to aquaculture lies in the human diet shift towards seafood with a low carbon footprint. Increasing the protein uptake from seafood while decreasing uptake of meat especially beef has a high potential for reducing methane and nitrous oxide emissions which are intensive in meat production (Springmann et al., 2018). This solution has been already analyzed by (Hoegh-Guldberg O. et al., 2019) with an estimated mitigation potential of 0.3 – 1.1 GT CO₂eq/ year by 2050. Project Drawdown is planning to include this solution as a part of the Drawdown Food System, similar to the solution called Plants-rich diet (Project Drawdown, 2020) therefore it is not included in the scope of current solutions.

Therefore, the scope of this solution is focused on cutting GHG emissions from on-site energy use of animal aquaculture (salmonids, carps, crustaceans, shellfish), specifically by shifting from diesel and petrol-based generators to hybrid systems that are partly based on renewable energy resources. Depending on the farmed species and farm type, aquaculture may be one of the most energy-intensive practices in food production (Stickney, 2010) with recirculating systems and shrimps aquaculture specifically consuming the highest amount of energy (MacLeod et al., 2020), thus while energy use grows in aquaculture, this sector may become vulnerable to increasing energy price volatility (Pelletier et al., 2014). The reliability of energy systems in aquaculture is an important matter as animals worth a lot of money are kept in the farm cages at once (Syse, 2016). Therefore, energy shortages often cause serious losses for farmers. Energy requirements in aquaculture vary widely depending on the local climatic conditions, type of farm and farmed species; e.g. low trophic level species such as mussels require fewer energy inputs while recirculating fish aquaculture systems demand high energy inputs (Ayer & Tyedmers, 2009; Troell et al., 2004). Specifically, offshore farms largely depend on fossil fuels (Syse, 2016). For example, 50 percent of Norwegian fish farms use diesel generators to produce electricity (Syse, 2016). Tracking energy use in aquaculture is associated with the whole production cycle, starting with broodstock unit, hatchery, live feed unit, and farmed unit (Ioakeimidis et al., 2013). It is projected that the use of energy-intensive aquaculture will increase due to climate change effects and the high demand for reliable food production systems (Costello et al., 2020). Thanks to Life Cycle Assessment studies, primary sources of global GHG emissions coming from aquaculture are available in published literature (MacLeod et al., 2020a) and via Seafood Carbon

Emissions Tool (Parker, 2021). To reduce GHG emissions coming from on-site energy use, a few studies proposed hybrid energy systems that combine traditional diesel and petrol generators with PV and Solar-Thermal panels or wind turbines (Ioakeimidis et al., 2013; Kim, 2018; Syse, 2016; Waite et al., 2014). The advantage of hybrid energy systems is that they are more reliable and normally have a lower electricity cost than systems relying on a single power resource in a long term perspective. Specifically for Norwegian salmon farms, the hybrid energy systems have the lowest costs of electricity generation over 20 years (Syse, 2016). Depending on the type of farm and location, solar or wind power can be chosen for the best performance. Solar PV panels have certain advantages as they require less maintenance than wind turbines; however, they have limited capacity in geographical areas where sun radiation is limited (Syse, 2016). Hybrid systems allow producing clean energy supported by traditional diesel/petrol generators with a backup system securing the electricity delivery to the farms that is crucial for the survival of farmed species. Hybrid systems are also by design using only the farm's available space and do not require additional land that otherwise would have to be acquired by the farmers, which might raise production costs (Ioakeimidis et al., 2013).

1.2 ADOPTION PATH

1.2.1 Current Adoption

The GHG emissions accounted for in this solutions are coming from the most current estimations of diesel and petrol usage in global aquaculture thus from the off-grid energy systems (MacLeod et al., 2020a; Parker, 2021). Therefore, the current adoption is set as zero, as we are only considering the transformation of diesel and petrol-based generators into hybrid systems partly based on renewable energy resources. The other aquaculture GHG emissions related to electricity production and usage are not included in the current analysis so that the current emissions are not coming from on-grid systems.

1.2.2 Trends to Accelerate Adoption

Both solar and wind power are characterized by exponential growth within the last decade. Technological advances and the international GHG emissions reduction agenda led to decreasing prices of renewable energy sources as well as its greater availability. The adoption scenarios have been built in line with the World Resource Institute report on “Creating a Sustainable Food Future” by using the current and predicted growth of global renewable energy supply as presented in major reports on energy transformation:

- International Energy Agency, World Energy Outlook 2018 draws a few scenarios: a) New Policies assuming 21 percent of electricity generation by 2040 coming from solar and wind, b) Current Policies assuming 16 percent of electricity generation by 2040 coming from solar and wind, and c)

Sustainable Development Scenario assuming 38 percent of electricity generation by 2040 coming from solar and wind power (IEA, 2018).

- Shell Sky Scenario assuming solar PV instalment annual growth rate will grow up to 20 percent by 2035 (Shell, 2018).
- Energy Watch Group 2019, assuming that by 2050, 69 percent of energy supply will come from solar PV and 18 percent from wind energy (Ram et al., 2019).
- Greenpeace Energy Revolution 2015 report, assuming annual growth rates of renewable energy supply by 2020 is between 23 and 41 percent, by 2030 between 5 to 19 percent and by 2050 between 3 to 5 percent (Greenpeace, 2015).
- Equinor 2020 report assuming that in 2050 between 28 to 49 percent of energy can come from solar PV and wind power (Equinor, 2020).

The startling pace of PV adoption globally has come as a surprise to most organizations including the International Energy Agency and the U.S. Energy Information Administration. Many organizations such as these have been inclined to raise their estimates for future PV growth with each successive report, as the ground reality of the market growth rates for both solar PV and concentrated solar power (CSP) have outpaced previous estimates. There is an agreement that the growth rate for solar PV will continue to be quite high for the future. Moreover, new onshore wind power capacity is projected to continue growing steadily with or without climate policies, showing that the technology is increasingly mature and cost-competitive with fossil fuels.

In this solution, the flexibility is given to the aquaculture producers to determine what type of energy hybrid systems they are willing to install. It largely depends on the geographical distribution as in some places solar PV is a viable solution while in other places the more viable option is wind turbines. Small wind/solar hybrid systems may compensate for seasonal variations in wind and sun availability each year to some extent. The fact that hybrid systems are proposed instead of energy systems fully based on renewable resources gives even more flexibility for the producers and reduces the capital investment costs of energy supply transformation.

1.2.3 Barriers to Adoption

Economic and policy aspects might cause barriers to adopting the Improve Aquaculture solution. As currently, the majority of aquaculture production is coming from emerging economies, the majority of the transformation has to take place there, especially in China and other Asian countries.

Nearly 90 percent of aquaculture production is in Asia (100% = 66.6 million tons)

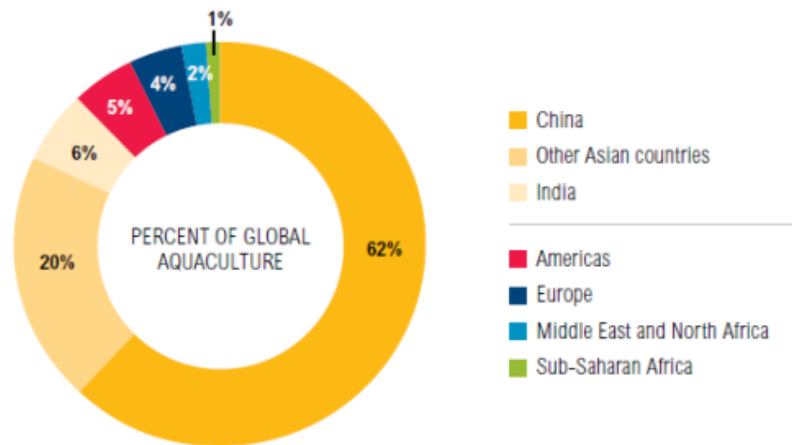


Figure 1.2 Aquaculture production in main world regions (Waite et al., 2014).

This may have limitations, even though China has put forward an agenda to become carbon neutral by 2060. Improvement of aquaculture operations carries additional capital investment costs which affect production costs. If the industry lack incentives for the producers, then they might have no willingness to improve their operations. First of all, the producers might not have the capital to make the necessary investments in innovation of their energy system and this is especially true for smallholders who operate with small profit margins and cannot access credit (Nandeesh et al., 2010). It is estimated though, that major producers from the Global South are commercially oriented, with ‘small-scale’ family farms contributing less than 30% of farmed fish production in these countries (Belton et al., 2018). Secondly, the price of consumer product does not always raise together with production costs, so it does not give enough offset to added costs. When the energy sustainability improvements are mandated by public regulations or private certification schemes, smallholder farmers may not be able to adapt and may be forced out of a market or out of aquaculture altogether. National energy policies have the potential to influence the energy production from aquaculture sector; however, it is important to highlight that governance, corruption, and infrastructure all provide additional constraints to improving aquaculture energy technology (Belton & Little, 2011). When the hybrid systems are specifically deployed at offshore farms, the operational costs might rise due to increased corrosion and extreme weather events (Syse, 2016).

In addition to economic and political reasons, lack of access to information might be a limitation to improve energy systems in emerging economies. Both a lack of skilled and experienced services, as well as limited access to educational materials and the most recent technologies, impede farmer innovation and uptake of new technologies and best management practices (Nandeesh et al., 2010). Moreover, it has been already

proved that lack of monitoring capacity has made it difficult for countries to enforce laws and regulations designed to improve aquaculture's environmental performance (Hishamunda et al., 2010).

1.2.4 Adoption Potential

The adoption potential of this solution is considerable, as aquaculture become a major source of seafood for the world's population. Aquaculture provides protein and nutrition to the world's population, including vitamins, fatty acids and important minerals such as zinc, calcium and iodine (FAO, 2020). Therefore, advancing aquaculture and transforming them to energy independent units is key to secure healthy and sustainable food for future generations. Because the growth of aquaculture is expected to continue, the importance of it to become sustainable has been already addressed by numerous organizations such as UN Global Compact initiative and World Resource Institute (UN Global Compact, 2020; Waite et al., 2014). Aquaculture sector has received many concerns regarding its sustainability and therefore the positive environmental image that coincides with the use of renewable energy could help this sector to change its appearance (Toner & Mo, 2002).

Both solar PV and Wind technologies are projected to be one of the most relevant technologies in future energy systems (especially onshore wind turbines). The majority of transformation has to come from Asian countries which are responsible for around 88 percent of world aquaculture production, with China alone accounting for 62 percent (The World Bank, 2013). Tropical countries may have advantages in their potential for using solar power in transformations away from fossil-fuel-based energy. China which is the major aquaculture producer has put forward a new action agenda and committed to becoming carbon neutral by 2060 (PRI, 2020). Therefore, replacing fossil fuel-based energy generators by renewables is in line with the national Chinese agenda and will likely be supported by the governmental institutions. Currently, China is the global leader of solar PV installation and out of the top 10 countries based on annual installed PV capacity in 2017, four nations were in Asia (China, Japan, India, and Korea) (BP, 2018). The same exponential trend of energy production from fossil fuel-based to solar and wind power based is also seen globally, and many reports are predicting further expansion of renewable energy resources used in future energy systems. The studies analyzing the feasibility of PV and Solar-Thermal installations for supporting electricity generation in aquaculture found that solar power can supply from 50 to 500 percent of electricity and that the payback period is 21 years for PV and 5 years for Solar-Thermal (Ioakeimidis et al., 2013).

1.3 ADVANTAGES AND DISADVANTAGES OF IMPROVE AQUACULTURE

1.3.1 Similar Solutions

The solutions from the Electricity sector namely Distributed Solar Photovoltaic, Onshore Wind Turbines, Offshore Wind Turbines assume replacement of fossil fuel-based energy by those renewable energy sources in the electric grid. In Improve Aquaculture solution, we are taking into consideration the replacement of diesel and petrol generators by hybrid systems that are partly based on renewables. This represents the part of external electricity generation in aquaculture, so it does not include the part of electricity derived from the grid. Therefore, those solutions are not overlapping in their climate impact calculations.

1.3.2 Arguments for Adoption

In addition to reducing GHG emissions from aquaculture operations, there are numerous advantages to adopting this solution, including:

- Shifting to hybrids systems partly based on renewables is a profitable action for the farmers because it provides long term financial profits.
- When farms are sourcing their energy mainly from the grid, farmers are experiencing losses and damages of their cultured animals when electricity shortages occur. This is an additional loss in their profits and becoming energy independent is within producers' interest.
- Improving aquaculture operations will support additional jobs in the aquaculture and renewable energy resources market. Installation of hybrid energy systems will lead to the further technological development of the sector.
- By advancing aquaculture, food and nutrition security increases and this is important for sustaining the future demand for food (FAO, 2020).
- Adoption of this solution allows achieving Sustainable Development Goals of UN, particularly goals 2 Zero Hunger, 7 Affordable and Clean Energy, 9 Industry Innovation and Infrastructure, 13 Climate Action, 14 Life Below Water.

1.3.3 Additional Benefits and Burdens

Here this solution is compared with other solutions in the ocean sector in terms of ecosystem, social and climate impact. Improving Aquaculture represents intermediate climate impact within all ocean solutions with high adoption potential and intermediate social benefits.

Table 1.1 Ocean Solutions Comparison.

Ecosystem Services is subjective based on impacts on biodiversity, habitat restoration, protection from extreme weather events etc. **Social Justice Benefits:** If a solution is causing a positive impact on local societies. **Climate Impact:** GHG reduction potential in GT CO₂ eq, 2020-2050: low >1, middle between 1 and 3, high <3. **Global Adoption Potential:** TOA in Mha: low > 100, the middle between 100 and 400, high < 400; TAM is applicable for only two solutions Improve Fishery and Improve Aquaculture therefore direct comparison with other ocean solutions is not possible, however, both solutions represent high total adoption potential. n/a – not applicable.

	Ecosystem Services	Social Justice Benefits	Climate Impact	Global Adoption Potential
Conventional fishery	Low	Low	n/a	n/a
Conventional aquaculture	n/a	Medium	n/a	n/a
Conventional seaweed farming	Medium	Medium	Low	n/a
Improve Fishery	High	High	Middle	High (TAM 94 million tons landings)
Improve Aquaculture	n/a	Medium	Middle	High (TAM 126 million tons live weight)
Seaweed Farming	Medium	Medium	High	High
Macroalgae Forests Protection	High	High	Middle	Middle
Macroalgae Forests Restoration	High	High	Middle	Middle
Coastal Wetlands Protection	High	High	Middle	Low
Coastal Wetlands Restoration	High	High	Middle	Low
Seafloor Protection	High	Medium	High	High

2 METHODOLOGY

2.1 INTRODUCTION

Project Drawdown's models are developed in Microsoft Excel using standard templates that allow easier integration since integration is critical to the bottom-up approach used. The template used for this solution was the Reduction and Replacement Solutions (RRS) which accounts for reductions in energy consumption and emissions generation for a solution relative to a conventional technology. These technologies are assumed to compete in markets to supply the final functional demand which is exogenous to the model but

may be shared across several solution models. The adoption and markets are therefore defined in terms of functional units, and for investment costing, adoptions are also converted to implementation units. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios (for the 2020-2050 segment¹) is what constituted the results.

2.2 DATA SOURCES

For the improve aquaculture model, the functional unit is in million tons of live weight of bivalves, crustaceans and fish produced (excluding algae) in aquaculture while the implementation unit is a facility for million tons of live weight. The primary source of data for aquaculture production is FAO 2020 report (FAO, 2020), and World Bank report (The World Bank, 2013). Based on those sources the projection of aquaculture production growth has been modelled. The data of greenhouse gas emissions from different aquaculture were extracted from Aquaculture Energy Use Database (FEUD) maintained by Dr. Robert Parker (Parker, 2021). Additional greenhouse gas emissions data were extracted from published meta-analyses addressing greenhouse gas emissions from global aquaculture (MacLeod et al., 2020a) and three Asian systems (Robb et al., 2018). The data of greenhouse gas emissions reduction rate in hybrid energy systems aquaculture were gathered from four sources (Ioakeimidis et al., 2013; Kim, 2018; Syse, 2016; Waite et al., 2014).

The projections of hybrid energy systems installation have been modelled following the World Resource Institute report on “Creating a Sustainable Food Future” assumption about applying the predicted growth of global renewable energy supply (PV and wind power) as presented in major reports on energy transformation (Equinor, 2020; Greenpeace, 2015; IEA, 2018; Ram et al., 2019; Shell, 2018).

Data of first and operational costs of aquaculture for conventional practice has been gathered from nine studies representing different systems and geography (Afero et al., 2010; Copeland et al., 2005; de Bezerra et al., 2016; De Ionno et al., 2006; de Oliveira et al., 2012; Gasca-Leyva et al., 2002; Gomes et al., 2006; Hermansen & Eide, 2013; Liu & Sumaila, 2007) and the difference between conventional and solution costs have been calculated using (Kim, 2018; Syse, 2016) economic analysis of hybrid aquaculture systems.

¹ For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2015-2050.

2.3 ESTIMATING THE ADDRESSABLE MARKET.

2.3.1 'Total Addressable Market' Definition

The addressable market for improve aquaculture is defined as total animal production in aquaculture thus is in million tons of live weight.

Based on a range of sources, we have an estimated total production of approximately 72 million tons in all areas worldwide in 2014. Aquaculture production is projected to increase to approximately 126 million tons globally in 2050. The sources for these data are (FAO, 2020; The World Bank, 2013). Future aquaculture production were projected from the data sources by extrapolating trends of current 2018 values and projected 2030 values. To ensure a real-time series of production data, we draw a set of trends based on the different types of growth rates (linear, S-shape growth) from both sources and choose the mean value as a final projection.

2.4 ADOPTION SCENARIOS

Two different types of adoption scenarios were developed: a Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

2.4.1 Reference Case / Current Adoption

Because this solution is predicated on the current data of GHG emissions from diesel and petrol-based electricity generation in aquaculture and its replacement by hybrid systems partly based on renewables, the current adoption is defined as zero tons of live weight.

2.4.2 Project Drawdown Scenarios

Nine custom adoption scenarios are projected with the following details.

1. ***Custom adoption scenario one:*** based on Greenpeace report REF scenario (23 percent annual growth rate by 2020, 5 percent between 2020 and 2030, 3 percent between 2030 and 2050) of solar power growth rate as a low case.
2. ***Custom adoption scenario two:*** based on Greenpeace report E[R] scenario (38 percent annual growth rate by 2020, 17 percent between 2020 and 2030, 5 percent between 2030 and

2050) of solar power growth rate as a low case – excluded from further analysis as is the final adoption if highly extreme.

3. ***Custom adoption scenario four:*** based on Sky Shell report scenario of solar power growth rate (solar power occupy 0.5% of the market in 2018, 32% of the market in 2050).

4. ***Custom adoption scenario five:*** based on Sky Shell report scenario of wind power growth rate (wind power occupy 0.5% of the market in 2018, 13% of the market in 2050).

5. ***Custom adoption scenario six:*** based on IEA 2018 report New Policies scenario on solar and wind power growth (solar and wind power occupies 6 percent of the market by 2017, 12 percent by 2025, 21 percent by 2040).

6. ***Custom adoption scenario seven:*** based on IEA 2018 report Current Policies scenario on solar and wind power growth (solar and wind power occupy 11 percent by 2025, 16 percent by 2040).

7. ***Custom adoption scenario eight:*** based on IEA 2018 report Sustainable Development scenario on solar and wind power growth (solar and wind power occupy 16 percent by 2025, 38 percent by 2040).

8. ***Custom adoption scenario nine:*** based on EWG 2019 report (solar power occupy 69% of the market in 2050).

9. ***Custom adoption scenario ten:*** based on Equinor 2020 report mean for solar and wind power projections (solar and wind occupy 28 and 49 percent of the market in 2050).

Impacts of improving aquaculture from 2020-2050 were generated based on three Project Drawdown scenarios (PDS), which were assessed in comparison to a *Reference* Scenario where the solution's market share was fixed at the current levels. For a conservative approach, two highest and three lowest scenarios has been excluded. The three PDS scenarios are:

Plausible Scenario - This scenario presents a conservative growth, which is represented by average of all eight custom adoption scenarios

Ambitious Scenario – This scenario presents an average growth, which is represented by the high of all eight custom adoption scenarios.

Maximum Scenario – This scenario presents an optimistic growth, which is represented by the single highest customized scenario based on EWG 2019 report.

2.5 INPUTS

2.5.1 Climate Inputs

Climate inputs in *Improve aquaculture* solution are direct emissions coming from on-site diesel and petrol usage in aquaculture. The data of greenhouse gas emissions from different aquaculture were extracted from the Seafood Carbon Emissions Tool maintained by Dr. Robert Parker (Parker, 2021). The database consists of data collected and calculated for many years using many sources, about GHG emissions associated with the production of seafood. Some additional GHG emissions data for the aquaculture systems not covered in Seafood Carbon Emissions Tool were extracted from recently published meta-analyses addressing GHG emissions from global aquaculture (MacLeod et al., 2020a) and FAO 2018 study of freshwater aquaculture in Asia (Robb et al., 2018). The emissions assigned only to diesel and petrol has been taken for the model as direct emissions per conventional variable. Emissions are available for different species/groups (27 species and 9 broader groups) and aquaculture systems (RAS, marine net, raceway, cages, ponds, rafts, longlines, bottom culture) and vary significantly. Therefore, to avoid over or underestimation of global GHG from all cultures species/groups, weights has been calculated and applied to the direct emissions variable based on data of global production of different culture groups (MacLeod et al., 2020b). As for the year 2017, the highest live weight of production was assigned to freshwater species (43 Mt – weight 0.58), followed by bivalves (15 Mt – weight 0.21), shrimps and prawns (7.9 Mt – weight 0.1), and marine species (7.7 Mt – weight 0.1) (MacLeod et al., 2020b). The data of GHG emissions reduction rate in hybrid energy systems were gathered from four sources (Ioakeimidis et al., 2013; Kim, 2018; Syse, 2016; Waite et al., 2014) and the average rate of GHG reduction has been applied to conventional direct emissions to come up with solution direct emissions (Table 2.1).

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Direct Emissions per conventional	t CO ₂ -eq/million tons of live weight	1,702– 684,107	299,999	45	3
The efficiency of solution (reduction in direct greenhouse gasses emissions)	Percent	48-57	53	4	4
Direct Emissions per solution	t CO ₂ -eq/million tons of live weight	808 – 341,598	155,128	41	3

Table 2.1 Climate Inputs

Note: Project Drawdown data set range is defined by the low and high boundaries which are respectively 1 standard deviation below and above the mean of the collected data points².

2.5.2 Financial Inputs

It is assumed that any costs for *Improving aquaculture* are borne at the landowner or manager level. Capital investment costs in aquaculture depend on the type of system (land vs. marine, open cages vs. RAS) but broadly consist of costs of building construction or adaptation, equipment, installation of farming system and installation of the energy system. The operational costs broadly consist of labour, feed, energy and fuel and maintenance. For the current analysis, the total capital investment costs (first costs) of aquaculture has been taken into consideration. Based on studies from different geographies and different farming systems first costs have been calculated on the facility for production of million tons of live weight unit. The operating costs are taken for the analysis only include costs of fuel, gas and energy, retrieved from studies from different geographies and farming systems.

The solution first and operational costs has been calculated using the calculated conventional costs, and applying ratio calculated based on two studies analyzing the economic feasibility of hybrid energy systems in aquaculture. According to those studies, the first costs of aquaculture with hybrid energy systems are much higher than for the traditional diesel and petrol-based systems (Table 2.2). On the other hand, the

² In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary.

operating costs of diesel and petrol-based systems are higher and require more maintenance as well as have lower lifetime capacity (Table 2.2).

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Conventional First Cost	Million US\$2014 per facility for million tons of live weight	1,544 – 4,962	3,253	16	9
Solution First cost	Million US\$2014 per facility for million tons of live weight	3,123 – 10,039	6,582	15	9
Conventional Operating Cost	Million US\$2014 per facility for million tons of live weight	74 - 408	242	16	9
Solution Operating Cost	Million US\$2014 per facility for million tons of live weight	45 - 212	129	14	9
Lifetime Capacity - Conventional	years	-	20	1	1
Lifetime Capacity - Solution	years	-	20	2	2

Table 2.2 Financial Inputs.

2.5.3 Other Inputs

Not applicable

2.6 ASSUMPTIONS

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that the infrastructure required for the solution is

available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at www.drawdown.org.

Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

Assumption 1: Global aquaculture production is assumed to continue to grow until 2050 at a similar rate as between 2018 and 2030.

Assumption 2: To account for differences in the amount of live weight production and associated GHG emissions between seafood groups, weights have been applied to the direct GHG emissions variable, based on production amount of different culture groups by region (MacLeod et al., 2020a).

Assumption 3: Adoptions of hybrid energy systems replacement of purely diesel-based systems in aquaculture follow trends of global adoption of renewable energy resources (including solar and wind power).

Assumption 4: As both solar and wind power has proved to be a viable solution for aquaculture energy systems, the differentiation between what types of renewables are installed is not made.

2.7 INTEGRATION

The complete Project Drawdown integration documentation (will be available at www.drawdown.org) details how all solution models in each sector are integrated, and how sectors are integrated to form a complete system. Those general notes are excluded from this document but should be referenced for a complete understanding of the integration process.

Only key elements of the integration process that are needed to understand how this solution fits into the entire system are described here.

Improve aquaculture is part of Drawdown's new Ocean sector. Integration of this sector with the other Drawdown sectors will be developed after all the Ocean solutions are complete.

The Ocean model

The Drawdown Ocean model classifies the ocean into 42 possible ocean zones using three dimensions:

1. "Cover and climate" dimension: a primarily physical climate- and bathymetry- and cover-based classification of the ocean into the following regions, 4 zones for the deep ocean (biological deserts,

equatorial waters, bloom waters and transition waters), 2 zones for shallow and slope waters (shallow waters and slope waters), and 1 ice-covered zone (sea ice covered waters).

2. “Access” dimension: there are political instruments in place that can limit how large parts of the ocean are used, the most common are Exclusive Economic Zones (EEZ) and Marine Protected Areas (MPA). EEZs are broadly defined by a 200 nautical mile offset from the seacoast of a country and as such collectively represent a significant fraction of the total ocean area. EEZs also coincide with the most accessible waters because of their definition; EEZ waters are closest to shore. And while EEZs tend to be shallow waters, they are not always shallow and can cross slope waters and extend into the deep ocean. The access dimension classifies whether waters are in or out of a national jurisdiction as defined by an EEZ.
3. “Depth” dimension: the open ocean can be broadly subdivided into three layers, the epipelagic (0 to 200 m), the mesopelagic (200 to 1000 m), and bathypelagic (1000 m to bottom). Since the bottom of the epipelagic zone corresponds to the maximum depth of the coastal or shallow waters, these two ocean zones are by definition excluded from the mesopelagic and bathypelagic layers.

Table 2 Project Drawdown Ocean model zones.

	Zone	Epipelagic	Mesopelagic	Bathypelagic
EEZ waters	Ice	23.39	15.44	9.48
	Shallow	17.75	-	-
	Desert	33.83	33.83	33.17
	Slope	34.72	34.72	27.65
	Equator	13.16	13.16	13.13
	Bloom	58.95	58.95	55.16
	Transition	19.47	19.47	19.01
Outside EEZ waters	Ice	17.20	17.07	16.71
	Shallow	0.155	-	-
	Desert	67.24	67.24	67.19
	Slope	28.18	28.18	25.83
	Equator	31.65	31.65	31.64
	Bloom	33.14	33.14	33.12
	Transition	60.45	60.45	60.33

2.8 SECTOR OF OCEAN-BASED SOLUTIONS

Project Drawdown has investigated eight ocean-based solutions and their potential to avoid GHG emissions or sequester carbon. The ocean-based solutions form two main groups: a group of protection and restoration solutions and a group of approaches to improving fisheries and aquaculture operation.

The protection and restoration solutions focus on blue carbon sinks, and their potential to sequester carbon. They include protection and restoration of coastal wetlands and macroalgae ecosystems, as well as seafloor protection from bottom trawling activities (Fig. 2-1). The adoption of protection solutions involves the expansion of marine protected areas and other conservation tools such as bottom trawling bans. The adoption of solutions focusing on restoration additionally requires active restoration programs. The climate impact of solutions from this sector, include avoiding carbon emissions or enhanced carbon sequestration and are designated for the government agency level.

The second group of solutions explores the potential of improving fisheries, improving aquaculture and seaweed farming. The fisheries can be improved by reducing fishing effort and restoring large fish biomass. The climate impact, therefore, includes avoiding carbon emissions from fuel usage and enhanced carbon sequestration in sunken large fish biomass and the implementation of this solution involve governments. Improving aquaculture solution assumes shifting from fuel-based energy systems to hybrid systems partly based on renewables, thus includes the climate impact based on avoiding GHG emissions. The seaweed farming solution explores the potential of expanding seaweed production and its climate effect on the enhancement of carbon sequestration in the deep sea together with unharvested biomass (Fig. 2-1). The agency-level for the two last solutions involves farmers.

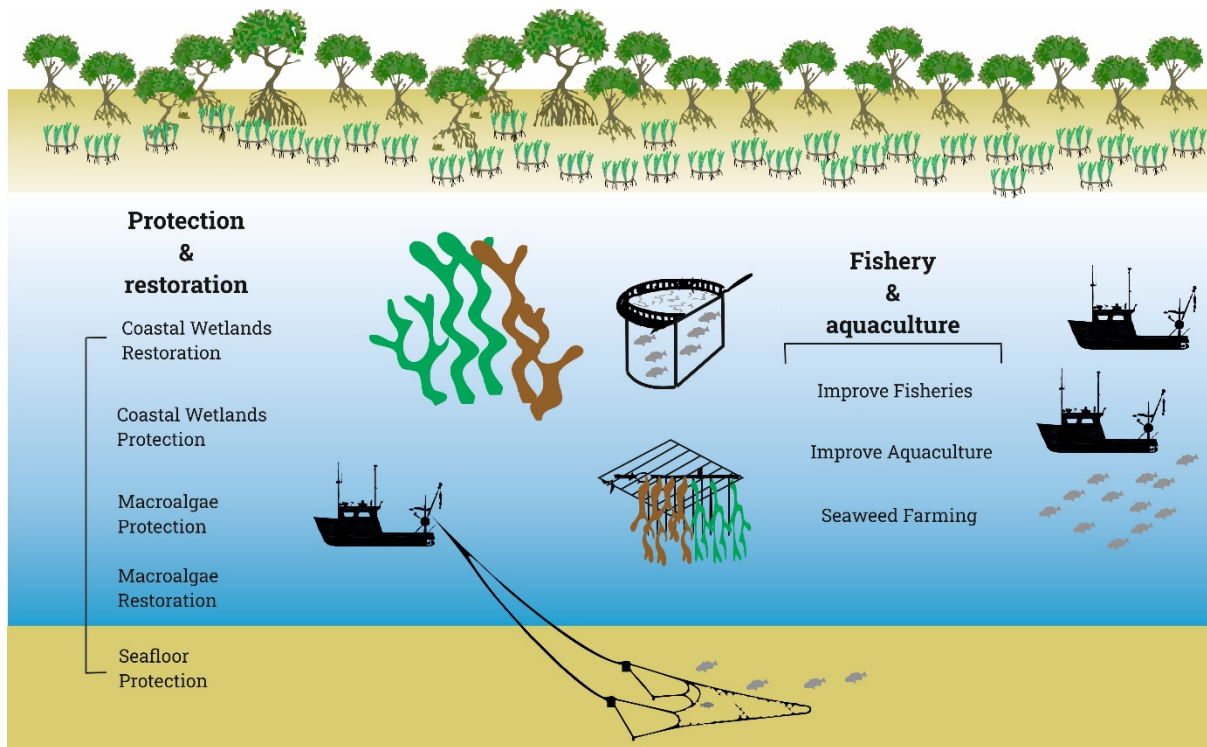


Figure 2.1 Schematic of all Drawdown ocean-based solutions.

3 RESULTS

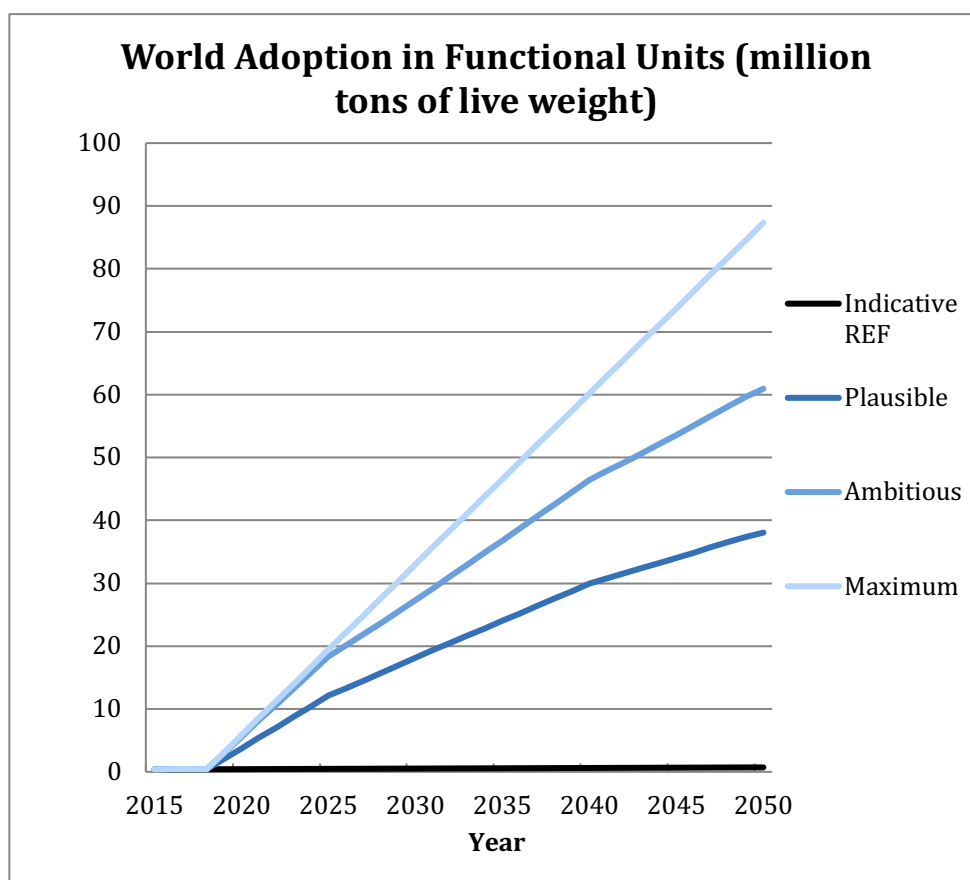
3.1 ADOPTION

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

For the reduction in GHG emissions from replacing traditional diesel-based generator by hybrid systems partly based on renewables, total adoption in the *Plausible* Scenario is approximately 38.05 million tons of live weight, representing adoption by 30 percent of global aquaculture. Total adoption in the *Ambitious* Scenario is approximately 60.93 million tons of live weight, representing adoption by 48 percent of global aquaculture. Total adoption in the *Maximum* Scenario is approximately 87.35 million tons of live weight, representing adoption by 69 percent of global aquaculture.

Solution	Units	Current Year (2018)	World Adoption by 2050		
			Plausible	Ambitious	Maximum
Improve aquaculture	million tons of live weight	0.41	38.05	60.93	87.35
	(% Market)	0.6%	30.1%	48.3%	69.2%

Table 3.1 World Adoption of the Solution.



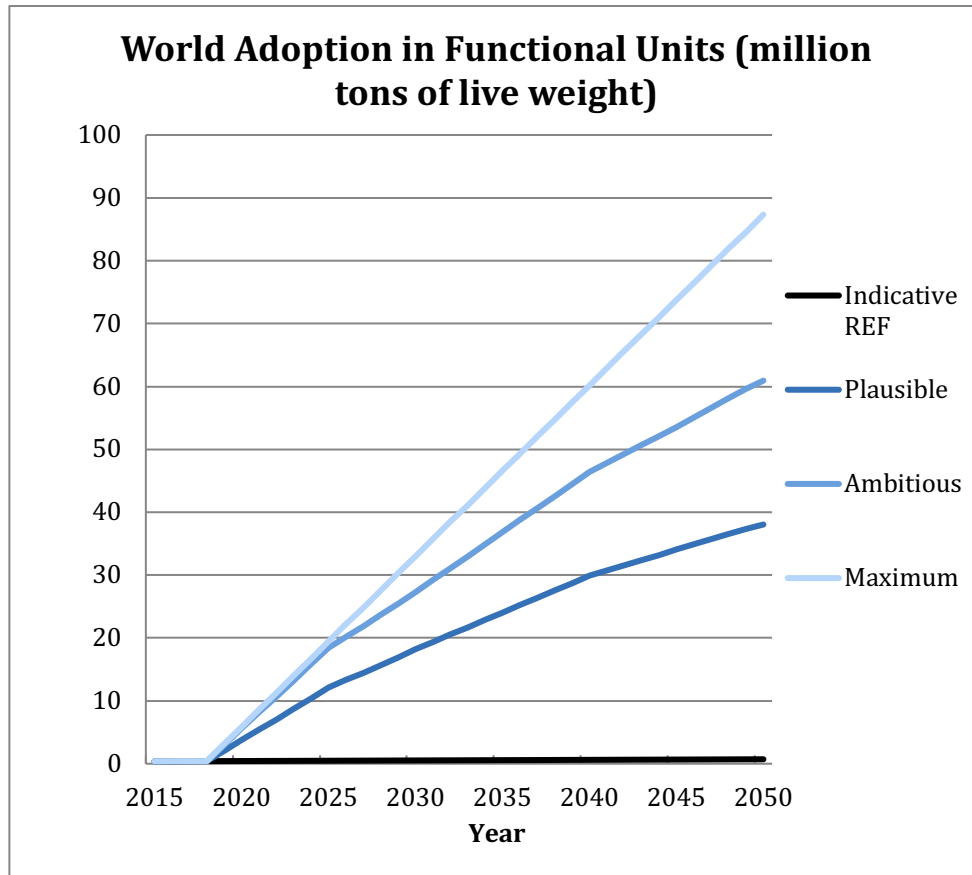


Figure 3-1 World Annual Adoption 2020-2050.

3.2 CLIMATE IMPACTS

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Climate impact for Improve aquaculture is 0.50, 0.78 and 1.02 gigatons of carbon-dioxide equivalent in the *Plausible*, *Ambitious*, and *Maximum* Scenarios respectively.

Scenario	Maximum Annual Emissions Reduction	Total Emissions Reduction	Emissions Reduction in 2030	Emissions Reduction in 2050

	(Gt CO ₂ -eq/yr.)	Gt CO ₂ -eq/yr. (2020-2050)	(Gt CO ₂ -eq/year)	(Gt CO ₂ -eq/year)
Plausible	0.03	0.50	0.01	0.03
Ambitious	0.04	0.78	0.02	0.04
Maximum	0.06	1.02	0.02	0.06

Table 3.2 Climate Impacts.

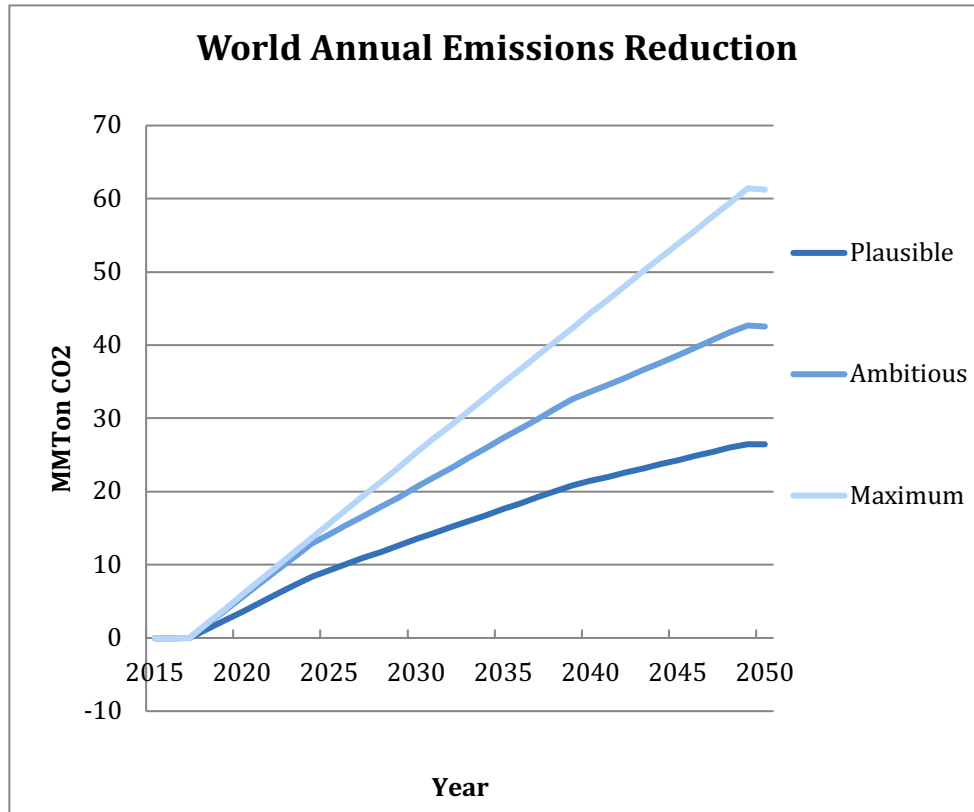


Figure 3-2 World Annual Greenhouse Gas Emissions Reduction.

Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	<i>PPM CO₂-eq (2050)</i>	<i>PPM CO₂-eq change from 2049-2050</i>
<i>Plausible</i>	0.041	0.002
<i>Ambitious</i>	0.065	0.003
<i>Maximum</i>	0.086	0.005

Table 3.3 Impacts on Atmospheric Concentrations of CO₂-eq.

3.3 FINANCIAL IMPACTS

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

For the *Plausible* Scenario, the lifetime cashflow savings NPV are negative US\$10.89 billion.

For the *Ambitious* Scenario, the net operating cost savings NPV are negative US\$18.86 billion.

For the *Maximum* Scenario, the net operating cost savings NPV are negative US\$21.34 billion.

Scenario	Cumulative First Cost	Marginal First Cost	Net Operating Cost Savings	Lifetime Operating Cost Savings	Lifetime Cashflow Savings NPV (of All Implementation Units)
	<i>2015-2050 Billion USD</i>	<i>2015-2050 Billion USD</i>	<i>2020-2050 Billion USD</i>	<i>2020-2050 Billion USD</i>	<i>Billion USD</i>
<i>Plausible</i>	340.84	151.37	85.84	140.48	-10.89
<i>Ambitious</i>	540.15	241.87	134.38	223.01	-18.86
<i>Maximum</i>	733.59	325.42	175.32	304.09	-21.34

Table 3.4 Financial Impacts

3.4 OTHER IMPACTS

Not applicable

4 DISCUSSION

Reducing the carbon footprint of ocean-derived food production has been regarded as one of the key actions by the High-Level Panel for Sustainable Ocean Economy (Hoegh-Guldberg O. et al., 2019). As the demand for food grows together with the global population, technological advances in seafood production techniques are high on the agenda. Depending on the farmed species or group and farm system type, greenhouse gas emissions from aquaculture vary considerably. The majority of the global emissions are assigned to activities related with feed production; however, there are limited solutions to replace current feed as the alternatives have other negative environmental consequences (MacLeod et al., 2020b). Therefore, replacing the on-site energy systems based on diesel and petrol by hybrid systems partly based on renewables is a viable solution to reduce greenhouse gas emissions from global aquaculture. Both solar PV and Wind technologies are projected to be one of the most relevant technologies in future energy systems (especially onshore wind turbines) thus installing hybrid systems in aquaculture is in line with the current energy transition trends (Waite et al., 2014). This solution also brings many benefits to the farmers as hybrid systems increase their independence and energy supply stability important for sustaining farmed organisms (Kim, 2018; Syse, 2016). Long-term financial benefits are also expected to occur together with new employment in hybrid energy systems sector.

4.1 LIMITATIONS

The major limitation is linked to the economic feasibility of farmers especially smallholders that lack the capital or access to credit (Nandeesh et al., 2010) and may experience financial risk if the production costs outpace the revenue. The government has an important role in providing incentives and support programs for the producers especially in emerging economies where the access to information and skilled services is limited.

4.2 BENCHMARKS

The World Resource Institute modelled different scenarios of emissions reduction in aquaculture (Waite et al., 2014) and one of the scenarios was based on shifting energy supply and assumed: "Energy resources for electricity production in 2050 reflect the current direction of energy policy in each major aquaculture producer country, resulting in a larger share of renewable sources in the global energy mix in 2050 relative to 2010". The report estimated greenhouse gas emissions at the rate of 775.8 Mt CO_{2e} in 2050 and a

reduction to 343.6 Mt CO_{2e} in 2050 in the shifting energy supply scenario. These values are higher than those estimated in this study because the shifting in energy supply concerns the total energy demand and supply, not only the ones coming from current diesel and petrol-based generators. Moreover, Waite et al. 2014 assume a hundred percent replacement of energy supply by renewables in aquaculture by 2050, an assumption that in our opinion is not actionable with the current technology and economy. Therefore, the difference in climate impact between Waite et al. 2014 and our study was expected.

Source and Scenario	(Ocean) Mitigation Impact (i.e. Gt CO _{2-eq} /year in 2050)
(Waite et al., 2014)	0.40
<i>Plausible</i> Scenario	0.04
<i>Ambitious</i> Scenario	0.06
<i>Maximum</i> Scenario	0.09

Table 4.1 Benchmarks

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6 GLOSSARY

Adoption Scenario – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

Approximate PPM Equivalent – the reduction in atmospheric concentration of CO₂ (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

Average Abatement Cost – the ratio of the present value of the solution (**Net Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

Average Annual Use – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

Cumulative First Cost – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis

period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

Direct Emissions – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

Discount Rate- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

Emissions Factor– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO₂e/kWh.

First Cost- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014\$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

Functional Unit – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

Grid Emissions – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell.

Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

Implementation Unit – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV's in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

Indirect Emissions – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

Learning Rate/Learning Curve - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experience is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

Lifetime Capacity – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**, and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

Lifetime Operating Savings – the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

Lifetime Cashflow NPV – the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

Marginal First Cost – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

Net Annual Functional Units (NAFU) – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

Net Annual Implementation Units (NAIU) – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU)**. This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

Net Operating Savings – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

Operating Costs – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014\$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

Payback Period – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

PDS/ Project Ambitious Scenario – this is the high growth scenario for adoption of the solution

PPB/ Parts per Billion – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

PPM/ Parts per Million – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

REF/ Reference Scenario – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

Regrets solution has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

Replacement Time- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

TAM/ Total Addressable Market – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

Total Emissions Reduction – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

Transition solutions are considered till better technologies and less impactful are more cost effective and mature.

TWh/ Terawatt-hour – A unit of energy equal to 1 billion kilowatt-hours