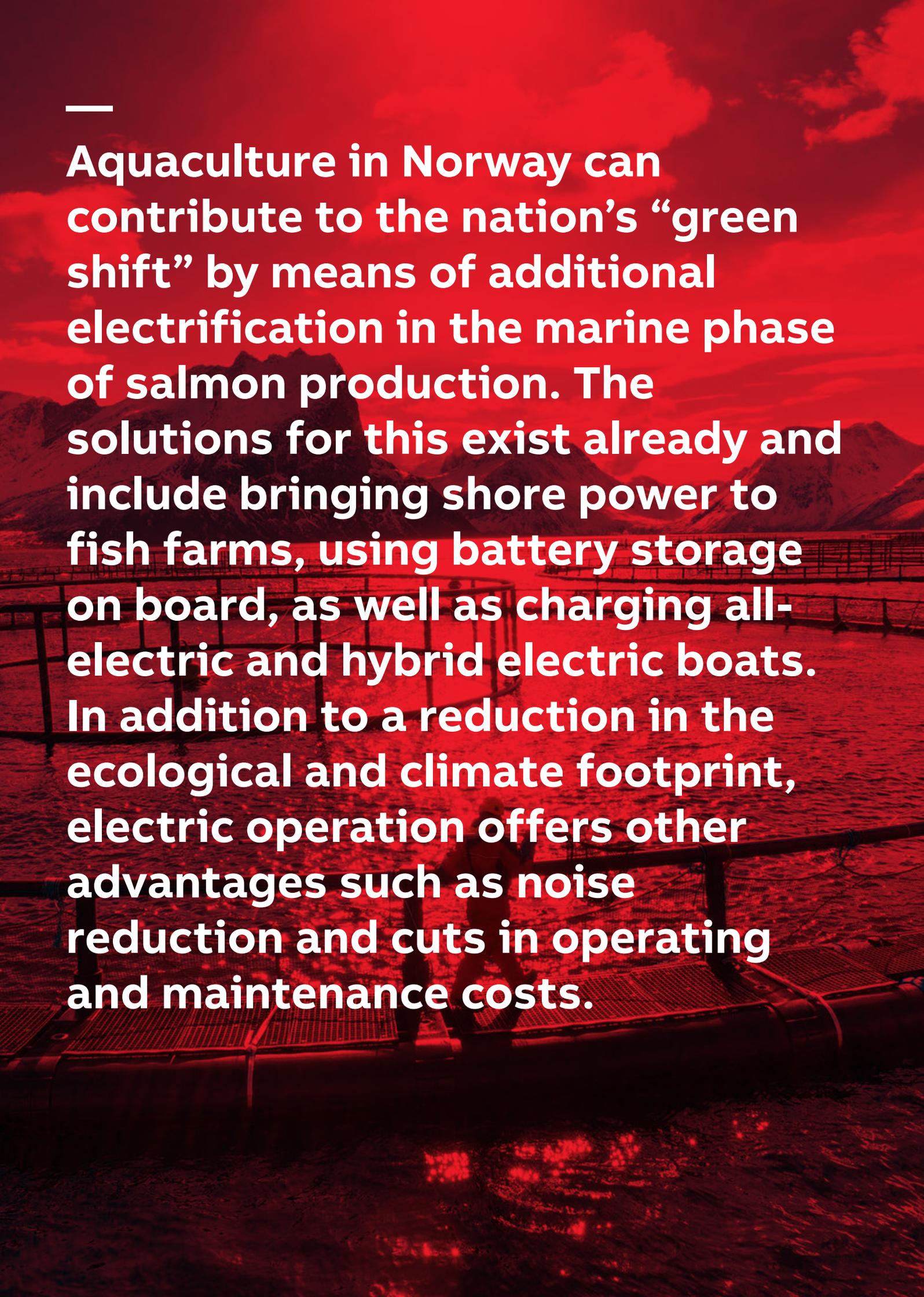


A green shift in Aquaculture

Switching salmon farming to power from shore can cut emissions by 300,000 tons of CO₂ in Norway

Additional electrification in the marine phase of salmon production can cut emissions corresponding to those of 150,000 cars.

Aquaculture in Norway can contribute to the nation's "green shift" by means of additional electrification in the marine phase of salmon production. The solutions for this exist already and include bringing shore power to fish farms, using battery storage on board, as well as charging all-electric and hybrid electric boats. In addition to a reduction in the ecological and climate footprint, electric operation offers other advantages such as noise reduction and cuts in operating and maintenance costs.

A red-tinted photograph of a salmon farm in Norway. In the foreground, a worker in a dark jacket and hat stands on a metal platform over the water, looking towards the background. The water is dark with some ripples. In the middle ground, there are several large, rectangular metal frames, likely part of the salmon farming infrastructure. In the background, there are snow-capped mountains under a cloudy sky. The entire image has a strong red color cast.

A green shift in Aquaculture

Additional electrification can cut almost 75 percent of the climate gas emissions from the marine phase of Norwegian salmon production. This would also represent a significant reduction nationwide. The measures presented in this study will cut the annual emissions of about 300,000 tons of CO₂. This is more than the emission cuts realized by all electric vehicles in Norway as of spring 2018.

The fish farming industry is already well underway with the shift in power supply to its marine installations from diesel-powered generators to renewable onshore energy. Nearly half the aquaculture installations nowadays are connected to the power grid. But, there is much to gain if the remaining installations are connected to the power grid and new technology is introduced for the ones that are already connected. This results in direct savings in diesel use for the power generator sets on the barges. Energy storage using batteries on barges and higher power supply all the way to the fish cage would also enable all-electric boat operation and charging. A systematic approach makes it possible to cut almost 80 percent of the current fuel consumption and a corresponding reduction of CO₂, NO_x, and SO_x emissions. This will be beneficial for the environment, climate, and occupational health and safety. It will also ensure that salmon production is geared for a future where every gram of climate gas emissions that can be cut should be cut.

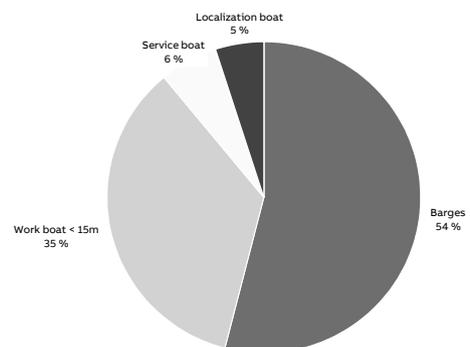
Emission cuts and reduced motor noise will also result in better occupational health and safety for the crews of boats and barges as well as local outdoor life and urban areas.

Shore power is a low-hanging fruit

The seafood industry and Norwegian authorities share a common desire for Norwegian seafood production to grow substantially in the coming decades. This will need to be accompanied by a simultaneous drastic cut in Norwegian climate gas emissions. Farmed salmon has a medium to low climate footprint compared to other meat production, but Norwegian salmon farming must also take responsibility for its share in Norway's emission cuts. At the same time, the growth in

Norwegian salmon production and cuts in the climate gas emissions of other industries necessitate larger relative emission cuts (per kg of salmon) than average per produced product. It is also sensible to pick the low-hanging fruit as quickly as possible. Shore power for salmon farming is the perfect candidate, and the industry is already well underway with the conversion. Combined with employing electric solutions on boats, it is possible to cut fuel consumption in the industry by almost 80 percent. CO₂, NO_x, and SO_x emissions will be cut by just as much. Emission cuts and reduced motor noise will also result in better occupational health and safety for boat and barge crews as well as local outdoor life and urban areas. The solutions presented in this feasibility study are currently available and can be provided by the Norwegian shipyards, suppliers and technology companies. Extensive use of these solutions will contribute to creating value and building up competence in environmentally-friendly technology which will strengthen the potential of Norwegian companies to export these solutions world wide to the aquaculture and marine transport industries.

Switching salmon farming to power from shore can cut emissions by 300,000 tons of CO₂ in Norway



Carbon reductions (tons of CO₂) realized by switching salmon farming to shore power by source per year.

A Stream of Advantages

Barges: electrification and energy supply

A large part of the Norwegian offshore aquaculture industry nowadays is connected to the onshore power grid by cables. There is no official overview of the actual number of farms. Based on our inquiries to large players in the industry, we estimate that around half of the aquaculture installations have shore power nowadays. The electrification of these marine farms has almost always been financially profitable. It is primarily the distance to a contact point ashore and the capacity of the power grid that determine the cost of laying a shore power cable. The closer to shore an installation is, the cheaper it will be to lay a shore power cable. The investment costs of installing shore power have paid off within a short period of time because of the low energy costs. Other financial advantages offered by shore power include reduced maintenance costs and downtime (the diesel-powered generators are kept as backup). In addition, farmers have reduced their CO₂, NO_x, and SO_x emissions. Along with a reduction in noise, the reduction in NO_x and SO_x emissions also result in better occupational health and safety at the farms.

The industry is moving in a direction where more and more farms are connecting to the power grid, in particular, in places with short payback time. It is technically possible to connect all remaining farms in Norway to the onshore power grid, but the average cost will presumably be higher than for those that have already connected to shore power. Certain, particularly remote locations could have a payback period that is so long that it is unlikely for them to switch over to shore power, but if they use public support schemes like Enova, a conversion could be profitable even for them.

Battery storage

Alternatives for saving fuel and cutting emissions exist even for locations where shore power is too costly or unfeasible. Power consumption on barges varies within a wide range; and as a rule, it is high during feeding and low before and after. To have enough power during feeding, the diesel-powered generator sets that supply power to the barge must therefore be dimensioned for the highest load. Fuel efficiency is poor at a low loads and correspondingly results in higher fuel consumption. The variation in power needs can be used to save diesel and reduce

emissions by introducing a battery that will supply power when consumption is low and will charge when the generator is working during feeding. This will make it possible to turn off the generator in between feeding periods, with substantial reductions in diesel expenses and CO₂, NO_x, and SO_x emissions.

The electrification of marine farms has almost always been financially profitable until now.

Extended power infrastructure

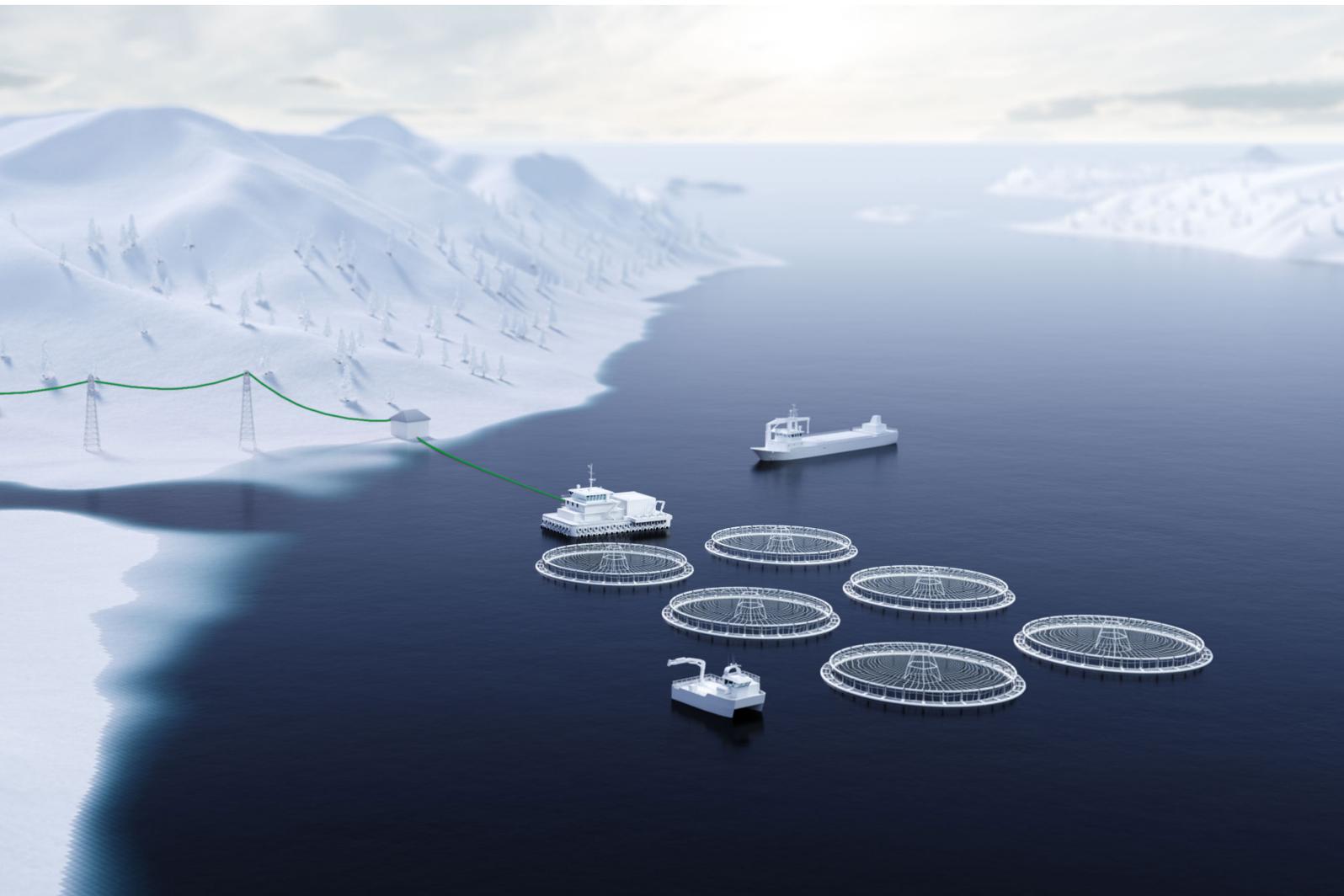
All locations that are already connected to shore power or can take advantage of the power grid will be able to set up extended infrastructure for power supply compared to the existing standard,



where power is only supplied for the consumption of the barge during feeding and for hotel operation. This is valid for the vast majority of locations in Norway and involves large potential emission cuts. The extended power infrastructure will allow more electrified vessels and make it possible for more of the machinery to switch over to electric operation. An extended power infrastructure makes it possible to charge electrical service- and work boats at shore, the barge, as well as the fish cage. Wherever the extended power infrastructure is available, it would be possible for service- and workboats to use clean power whether or not they are all-electric or hybrid-based. Most of these boats will have a battery pack that is large enough to drive the boat one way to or from the location of the farm. With charging options available both at the farm location and at shore there will be no need to use fossil fuels in day-to-day operations.

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The extended power infrastructure will allow more electrified vessels and make it possible for more of the machinery to switch over to electric operation.

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Additional electrification can cut almost 75 per cent of the climate gas emissions from the marine phase of Norwegian salmon production.



Batteries and power supply

The installation of battery packs can cut emissions even further in farm locations which are already supplied with shore power or are about to make the switch to it. Many farm locations supplied with shore power currently have limited power supply because of capacity limitations in the onshore power grid. This acts as a deterrent to the additional electrification of equipment and boat charging infrastructure, since the grid does not offer enough power. A battery pack combined with a power management system can solve this problem if the battery is charged during off-peak periods and then used in peak consumption periods. This also makes it possible to consume power above the capacity ceiling of the power grid and exercise active power management to minimize consumption cuts, thereby reducing power costs. A battery makes it possible to quickly charge work boats as well as use electric, energy-intensive equipment such as the fish cage seine washers. All-electric operation of hybrid or all-electric work boats and use of shore power to the fish cages for net washers reduce emissions.

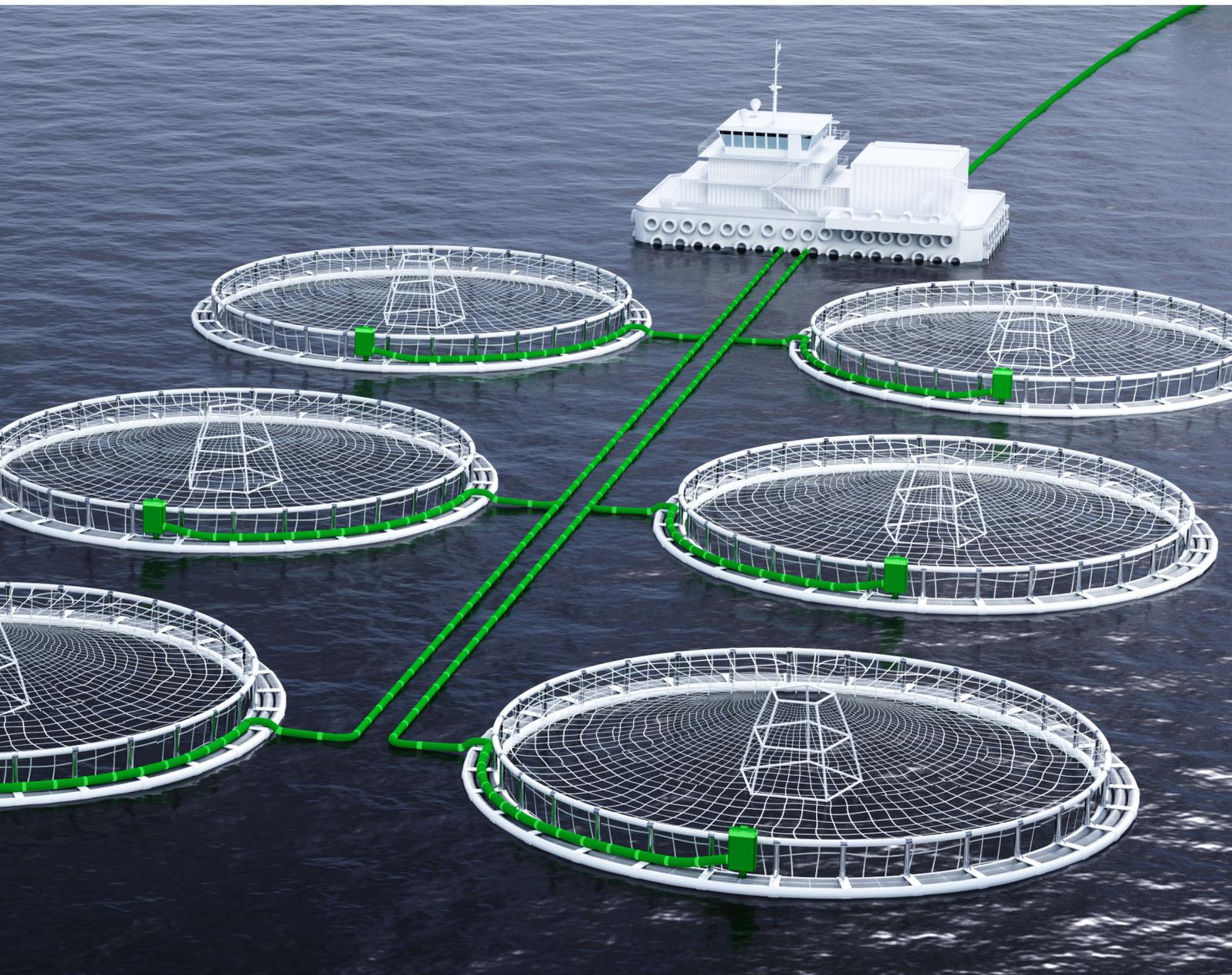
The installation of battery packs can cut emissions even further in farm locations which are already supplied with shore power or are about to make the switch to it.

Electrification of boats

The development of electric and hybrid electric propulsion systems and charging infrastructure for the marine sector in recent years has not yet fully reached the marine aquaculture sector. Individual companies have invested in hybrid electric work boats (under 15 meters) and have installed, on somewhat larger boats, battery packs for reducing fuel consumption during off-peak periods or short stays ashore. These are areas that offers large potential for improvement and emission cuts. The solutions are already available on the market and are getting better and better. The Norwegian shipbuilding industry is underway with the development of several all-electric work boats. Powerful electric outboard motors (with a power output corresponding to 80 hp) are already available



on the market and could meet a large part of the demand for propulsion in smaller boats used for passenger transportation and minor jobs at the fish pens. It is not profitable to install hybrid or all-electric propulsion on new or old work boats compared to standard diesel motors. However, this is only a matter of time, since battery prices are continuously falling, and a larger market will



significantly reduce the cost of hybrid or all-electric propulsion systems. All-electric boats could become financially profitable before hybrid ones because they will have less complicated machinery, less need for maintenance and will save space in the hull. Once demand and production pick up and battery prices fall in a couple of years, they will likely be cheaper to manufacture.

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Shore power to aquaculture farms can include battery storage on board as well as charging of all-electric and hybrid electric boats.

Future Solutions

This feasibility study is exclusively based on technology that is already available on the market. All solutions are not necessarily more profitable than diesel operation at the moment, but they will presumably become so in a couple of years, once battery prices have dropped even further, and the market as well as the availability of electric propulsion systems for boats have picked up among shipyards.

The future tax scheme for fuel and electricity will also be important. An increase in carbon tax will lower the threshold of profitability and will presumably allow more locations to get shore power. The same applies to the use of subsidy schemes like Enova, which contribute with subsidies in making electrification of locations more profitable or less cost-demanding for companies.

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Solar cells, wind power, and hydrogen-powered fuel cells are alternative ways to achieve zero emissions.

Sun, wind, and fuel cells

New methods of operation, locations, and alternative forms of energy are also important factors to assess. Since part of today's aquaculture

farms powered with generator sets are situated far away from the shore, other choices than shore power could perhaps be the preferred choice for achieving emission cuts. Solar cells, wind power, and hydrogen-powered fuel cells are alternative ways to achieve zero emissions, but remain largely unproven until this day. Today's technology for renewable power production will require additional space than that which is available on the barges, even if the reduction in fuel consumption can already make up for it to some extent. On the other hand, renewable power production combined with power management and battery storage on a larger scale than that which is used today is a possibility. Floating wind and solar power installations can be placed right next to the farms and produce power locally. Where there are no sensible solutions, for example, for mobile, seagoing forms of production, hydrogen-powered fuel cells can be a good alternative in the future.

Connecting offshore power production

It is also possible to connect offshore, stationary aquaculture installations to larger renewable power production facilities that are currently supplying power to the mainland. Floating offshore wind farms are planned in several locations, and the offshore aquaculture installations could perhaps be connected to these by cable at a lower cost than using shore power.

About Bellona and ABB

The Bellona Foundation is an independent environmental non-profit organization that works to solve the world's climate challenges, among other things, by identifying and implementing sustainable climate solutions. The Foundation works towards reaching greater ecological understanding as well as protection of nature, the environment, and health. Bellona is committed to the most important current national and international environmental questions and issues around the world.

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Prerequisite

The boats used in salmon farming in Norway nowadays vary widely in terms of size, fuel consumption, and potential for immediate electrification and emission cuts. The focus in this feasibility study is on boat types involved in the day-to-day or routine operation of the farms. In other words, light boats for passenger transportation or small jobs (location boats), work boats or catamarans with a length of less than 15 meters (work boats), as well as larger vessels for heavier operations (service boats). It is assumed that all boat types will be electrified, either using all-electric or hybrid propulsion. Regardless of the type, it is the share of operation using electricity that is assessed here, since this is what will have an effect on emissions. We assume that work boats could be operated all-electrically, whether with or without shore power, based on the batteries and motors available on the market nowadays. We assume that work boats can be operated all-electrically at locations that have or will have shore power because of the charging options at the barge, fish cage, or on shore. For locations which do not have shore power, we assume a 43 per cent cut in diesel consumption compared to today's consumption (hybrid boats), with charging only at the land base. Farms that do not have shore power are normally situated far away from the shore. For many of these, the distance from the land base to the barge will also be longer, which will result in higher fuel consumption for the work boats. We have assumed 50 per cent higher fuel consumption for this type of work boats. The normal battery capacity of currently existing batteries for hybrid electric work boats then limits emission cuts to 43 per cent of the consumption. We assume that service boats can cut their emissions during work on location (this is only what is factored in) by around 20 per cent as a result of using hybrid systems with on-board batteries. We assume that locations that

have or get shore power can cut their emissions by 100 kW of power supplied to the boats. We assume that 578 marine locations for salmon farming will be in operation at any time (figures from 2017 from the Norwegian Directorate of Fisheries), with one work boat and one location boat in daily use per location. In addition, we assume 50 days of use for service boats per location per year.

Battery storage

In addition, a number of other boats are used, to a smaller or larger extent, in aquaculture. These include barges, well-boats, etc. Where these have hybrid electric systems or options for connecting to shore power, they could also reduce their emissions somewhat during lay time at the fish cage or the barge, but this is not taken into consideration in the calculations in this feasibility study.

For locations which do not have shore power, we assume that diesel consumption can be slashed using batteries and power management on the barges. The diesel-powered generator sets could work during feedings, when the need for power is at its highest. When the generator is in operation, the batteries will charge so that they can provide power for heating, light, as well as other "hotel operation" in between feedings. This will make it possible to keep the generator set off for about two-thirds of the time, thereby cutting diesel consumption by 30 per cent due to efficiency losses at lower loads.

We assume that power supply using shore power cable could supply 350 kW to all locations that can get shore power. If a battery and power management system are added, the system could also take loads higher than 350 kW. It would then be possible to simultaneously supply the boat(s), feedings, hotel operation, and, for example, fish cage seine washer with more than 350 kW of power.

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Overview of fuel consumption and emissions divided by source per year.

Operation	Consumption (m3)		Emissions (tonnes)			Reduction potential (tonnes)		
	Diesel	Gasoline	CO ₂	NO _x	SO _x	CO ₂	NO _x	SO _x
Work boat < 15 m	42,194	0	111,392	1013	51	104,973	910	45
Service boat	28,900	0	76,296	694	35	17,544	159	8
Location boat	0	6,976	16,688	0	0	16,688	0	0
Barge	72,420	0	191,188	1,738	87	163,488	1,486	74
Floating renewable	0	0	0	0	0	774	7	0
Sum total	143,514	6,976	395,563	3,444	172	303,468	2,563	128

Contributors

We would like to thank the Lerøy Seafood Group for sharing information about shore power connection and fuel and power consumption on vessels, barges, generator sets, and during work operations. We would also like to thank Bremnes Seashore, Cermaq Norway, Grieg Seafood, Langøy laks, Nordlaks, Nova Sea, and Salmar for sharing data about the shore power connections to their fish farms. Finally, we would like to thank Gwind for information about energy solutions and production of solar and wind power on fish farms.

About the feasibility study

This feasibility study about switching salmon onto shore power is a collaborative project between Bellona and ABB. The underlying data was collected during the winter and spring of 2018 and reflects the situation and opportunities for Norwegian aquaculture during the same period.





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