Chapter 10
Economics of Multi-use and Co-location

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Abstract Under the right circumstances, multi-use of a marine site through co-location of complementary activities can result in more efficient use of ocean space. We explore the economic dimension of multi-use and co-location, using the general example of an aquaculture operation co-located within an ocean wind farm. Co-locating aquaculture operations and wind farms can produce both public and private benefits (cost savings). The public benefits arise from the fact that an aquaculture operation co-located within the boundaries of a wind farm does not negatively affect the ecosystem services derived from the ocean area it would otherwise have occupied. The private benefits are cost savings that arise from shared permitting, infrastructure, and logistics efforts and systems. The economic value associated with these benefits depends on the scale, location, and nature of the co-located ventures and the natural resources they affect. For locations in open ocean and relatively low-value coastal waters that are candidates for wind farm or aquaculture sites in most countries, the public benefit is likely to be on the order of 500−3,000/year per hectare of area occupied by the aquaculture operation, and the private benefits are likely to be less than $50–100/ton of aquaculture operation output.

10.1 Introduction

Under the right circumstances, multi-use of a marine site through co-location of complementary activities can result in more efficient use of ocean space. In this chapter, we explore the economic dimension of multi-use and co-location, using the general example of an aquaculture operation co-located within an ocean wind farm.

We begin with a review of ocean space as a potentially scarce resource that can be an input to a range of productive economic and ecological processes. In some

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cases, competing uses may be incompatible in a given location (for example, dragging for wild scallops cannot easily be co-located with on-bottom or floating moored aquaculture operations). In other cases, multi-use may be feasible (for example, floating finfish cages or shellfish longlines in the open spaces between wind farm towers). It is in the interest of society, and of marine resource managers in particular, to identify and promote the most valuable use (or combination of uses) of each piece of ocean space. To do this, it is necessary to understand the economic and ecological production functions for which ocean space is an input.

We then consider the way in which co-location of activities can result in private and public economic benefits. Private benefits may arise from cost savings due to shared use of planning and permitting investments, infrastructure, logistics, supply lines, communication facilities, etc. Public benefits may arise from the accommodation of more economic activity within a smaller footprint, which leaves more ocean space for other uses and reduces losses in ecosystem service value from incompatible uses of ocean space.

We conclude with a summary of what is the likely scale of economic benefits from co-location, and summarize results from a case study of mussel culture and wind farms in the Netherlands.

10.2 Ocean Space as an Input to Economic Production

Ocean space is a heterogeneous resource that serves as an input to numerous economic and ecological production processes. Particularly near the coast, where biological and ecological production is concentrated and where economic and recreational/aesthetic uses are most intense, ocean space may be in short supply and heavily contested. Marine spatial planning activities in many regions of the world are undertaken to manage competing uses of ocean space and promote efficient use of scare marine resources, particularly in coastal areas. Examples include ongoing regional ocean planning activities in the United States under the auspices of the US National Ocean Council, such as the Northeast Regional Ocean Plan (Northeast Regional Planning Body 2016), and the German marine spatial plan (Bundesamt für Seeschifffahrt und Hydrographie 2016) (Fig. 10.1).

A number of transitory and non-transitory uses can compete for ocean space. Transitory uses include:

- Commercial fishing (trawls, seines, dredges, longlines, gillnets, handlines)
- Recreational fishing
- Military operations
- Maritime shipping
- Yachting and recreational boating
- Whale watching
- Diving

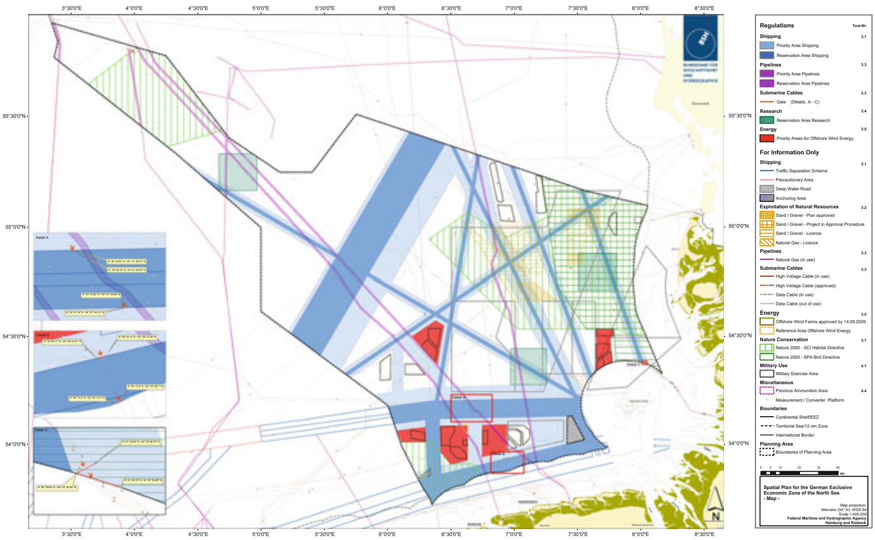


Fig. 10.1 Marine spatial plan for Germany's North Sea waters (Bundesamt für Seeschifffahrt und Hydrographie 2016)

Non-transitory uses include:

- Commercial fishing (traps/pots, weirs)
- Navigation channels
- Deepwater ports
- Wind farms
- Aquaculture sites
- Ocean dumping sites
- Shipwrecks
- Pipelines
- Marine protected areas
- Aesthetic viewsheds

The characteristics of a given area of ocean space make it more or less valuable to different uses. For example, the characteristics that determine the value of an area of ocean for marine aquaculture include distance from shore facilities (ports), nutrient fluxes, plankton densities, water temperature ranges, wind and wave conditions, current flows and flushing rates, prevalence of predators and parasites, marine contaminants, etc.

Because ocean space is of varying quality in this sense, it will produce a gradient of (potential) resource rents from alternative uses. At the same time, those uses may result in external effects if resources are degraded due to pollution, for example, or if opportunity costs arise due to forgone other uses of the space.

Historically, ocean space has not been allocated through private markets, but has instead been assigned to competing uses by pre-existing policies, implied legal interests based on tradition, and public trust considerations, among others. Historical (especially transitory) uses may have a priority in these processes. Allocation decisions are typically spread across multiple agencies. Multi-use allocation decisions will have to be made in the context of these established mechanisms.

10.2.1 Production Function

In making that happen, an economic framework is likely to be useful. The coastal and marine resources and coastal infrastructure of a geographic region can be thought of as inputs to ecological processes and economic activities that generate the value (wealth) that flows from that region's ocean resources. Understanding this "production function"—how resources and infrastructure contribute to economic value—is important if ocean resources are to be managed and used for maximum sustained benefit. A common way to measure that benefit is to quantify (estimate) the economic value generated by the economic and ecological processes that use the resources. In the following pages, we review briefly the state of knowledge about the links between marine resources and value generation. This information can suggest the scale of certain economic benefits that may flow from co-location.

Economic value exists only in the context of human populations and societies. One important determinant of economic value, therefore, is the people who participate in and receive benefits from the economic activity. The market and non-market value generated from marine resources is, in part, a function of how many people live, work, and play in the coastal and ocean areas in question, and how many visitors and tourists come to the region. There are some exceptions to this, especially in the more basic categories of ecosystem service values. For example, the value of carbon dioxide (CO_2) uptake by coastal and ocean waters is largely independent of the population living near those waters. But most categories of value will rise and fall with the number of participants; and that number can change because of population trends, changes in tourism, changes in recreational preferences, changes in wealth distribution, and other socioeconomic factors.

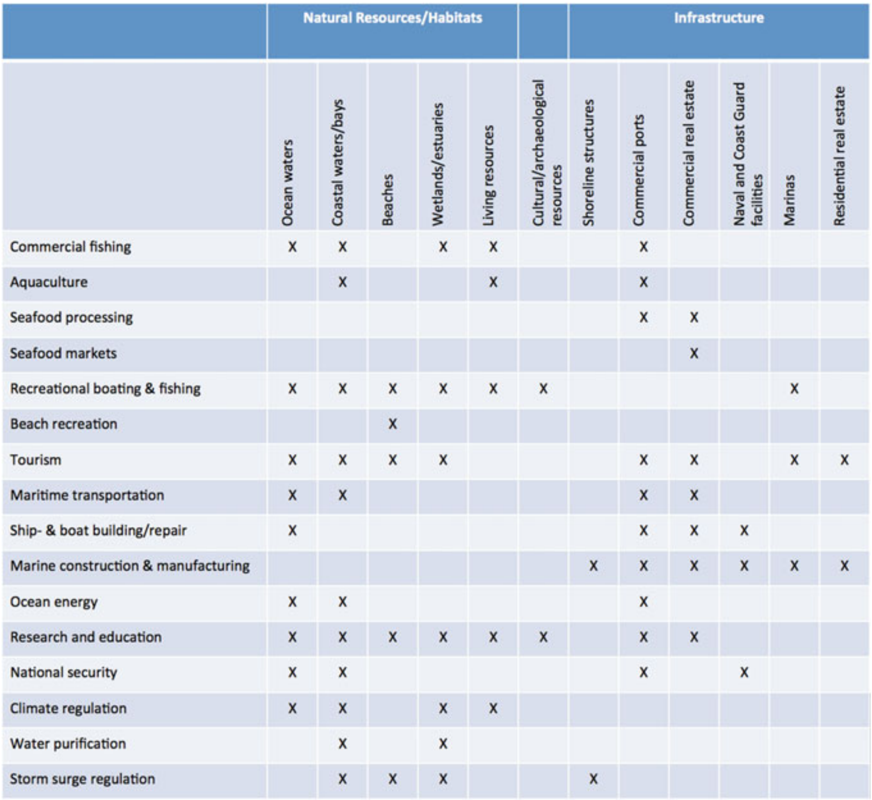
Value arises from marine resources because they provide ecosystem services and products and services, some of which are traded in markets. The Millennium Ecosystem Assessment (MEAB 2003) framework suggests the following classification of ecosystem services derived from coastal and marine resources:

- Provisioning Services
    - Food (fisheries, aquaculture)
    - Sea water
    - Biochemical and genetic resources
    - Minerals and other physical resources

- Regulating and Supporting Services
  - Climate regulation (CO_2 uptake, heat exchange)
  - Water purification (filtration, dilution)
  - Flood/storm protection
  - Erosion control
  - Waste assimilation
  - Nutrient cycling
  - Primary production
- Cultural Services
  - Beach recreation and coastal access
  - Recreational boating, fishing, diving
  - Aesthetic, spiritual, and cultural uses of the coast and ocean
  - Existence/bequest value of local species (value attributed by people to knowing that species exist, and will survive for future generations)

Figure 10.2 illustrates how different subsets of marine resources and infrastructure contribute to economic value generated in different economic activities and ecosystem service functions (climate regulation, water purification, and storm surge regulation) that are not captured by market data. The table is not exhaustive, but illustrates two important points. First, each natural resource and infrastructure component typically supports value generation in a variety of economic sectors and ecological functions. And second, different ocean economy sectors depend on different combinations of resources and infrastructure.

Although we know in principle which resources are used as inputs to which categories of ecosystem service and value, as suggested by Fig. 10.2, our ability to predict how changes in resources and infrastructure might affect value generation is, in most cases, incomplete at best. That is because the relationship between inputs (natural resources, infrastructure) and outputs (e.g., seafood, or recreation days) and the value of those outputs is often complicated. For some economic activities, the simple existence of access to a category of resources is sufficient: for example, the maritime transport industry needs port infrastructure and access to coastal and ocean waters to generate value; but that value does not increase, as a rule, when coastal water quality is improved. Furthermore, different areas of the ocean may have different levels of value to the maritime transportation sector, depending on their location relative to preferred shipping routes. On the other hand, the value generated by activities such as commercial fishing, aquaculture, and recreational boating and fishing depends both on the quantity and quality of coastal and ocean water resources (Hanemann et al. 2005; Keeler et al. 2012).



	Natural Resources/Habitats						Infrastructure					
	Ocean waters	Coastal waters/bays	Beaches	Wetlands/estuaries	Living resources	Cultural/archaeological resources	Shoreline structures	Commercial ports	Commercial real estate	Naval and Coast Guard facilities	Marinas	Residential real estate
Commercial fishing	X	X		X	X			X				
Aquaculture		X			X			X				
Seafood processing								X	X			
Seafood markets									X			
Recreational boating & fishing	X	X	X	X	X	X					X	
Beach recreation			X									
Tourism	X	X	X	X				X	X		X	X
Maritime transportation	X	X						X	X			
Ship- & boat building/repair	X							X	X	X		
Marine construction & manufacturing							X	X	X	X	X	X
Ocean energy	X	X						X				
Research and education	X	X	X	X	X	X		X	X			
National security	X	X						X		X		
Climate regulation	X	X		X	X							
Water purification		X		X								
Storm surge regulation		X	X	X			X					

Fig. 10.2 Mapping resources to economic sectors and value generation (adapted from Kite-Powell et al. 2016)

10.2.2 Unit Values

In general, the economic value of a resource or infrastructure component is best estimated at the margin, that is, in the context of a question such as "what is the value of an additional square kilometer of coastal wetlands to a region's seafood or coastal tourism industries," or "what is the value of an additional kilometer of beach to a region's coastal recreation benefits"? The value per unit area of an incremental piece of marine habitat, for example, depends not only on the location and characteristics of that piece, but also on how much of that kind of habitat already exists in the regional ecosystem. For these reasons, estimates of unit value (dollars per square kilometer, or dollars per year per square kilometer) for natural resources should generally be treated with caution.

The economic value of some marine ecosystem services, including the provision of seafood and other marine products, and certain recreational amenities, can be estimated from prices and quantities of goods and services traded in markets ("market values"). Other ecosystem services generate values that affect human wellbeing but are not observable from market transactions. These include the non-market or intrinsic values derived from walking on a beach, for example. There is some overlap between ecosystem service values and market values: for example, the primary production that supports biological populations of food fish is an ecosystem service, and its value is (partially) reflected in the commercial fisheries landings data.

Most ecosystem service values cannot be observed from prices in markets, and therefore must be estimated by quantifying the ecological service produced (for example, tons of CO_2 absorbed by the ocean waters of the North Atlantic each year) and then applying a unit value (in this case, the cost imposed by adding a ton of CO_2 to the atmosphere—see US EPA (2016). Published estimates of ecosystem service value from marine environments around the world span a very wide range, from near zero to more than \$100 million/year/km^2 (\$1 million/year/ha), depending on the location and the specific values included and assumptions used in the estimation. Using ecosystem service values in any particular planning context requires careful attention to the ways in which resources are used and valued, and the consequences of incremental management actions (Johnston and Russell 2011). Ecosystem service value estimates are broadly indicative of orders of magnitude for ecosystem services, but, as planning tools, they should be used with care.

In estimating the economic value derived from ocean space (habitat) in a particular location, it is necessary to take into account the particular qualities of local coastal and marine resources, and the socio-economic context of nearby populations. In general, this requires a location-specific analysis. Where no such analysis has been carried out, it is sometimes possible to develop rough estimates of economic value using a "benefit transfer" technique (see below).

Initial efforts to integrate results of ecosystem valuation studies from different locations can be found in Costanza et al. (1997). More recently, researchers have developed several databases, including the Ecosystem Services Valuation Database (Plantier-Santos et al. 2012; Texas A&M University 2016) for the US Gulf of Mexico, that summarize results of valuation studies from many locations. Table 10.1 presents summaries of values for different types of ecosystems from the meta-analysis by de Groot et al. (2012). Note that the point estimates summarized in Table 10.1 are typically derived from several studies conducted for different locations and different value categories.

Shoreline areas, and in particular beaches, provide significant value as aesthetic and recreational resources. Pendleton (2008) summarized studies suggesting that beaches along the coast of the United States see a total of approximately 800 million beach-visit-days per year. Those beach visits provide total recreational value of \$7—35 billion/year (2014 US\$), or about \$0.25 M/km^2/year for the average coastal land area (assuming approximately 9300 km of US coastline, excluding Alaska, and an average width of coastal recreation area of 100 m, or 0.1 km^2/km of coastline). The unit value of popular beaches is significantly higher

Table 10.1 Summaries of value estimates from ecosystem valuation studies

	Ecosystem service value, 2014 US$M/km^2/year			
	Marine waters (open ocean)	Coral reefs	Coastal systems (incl. sea grass)	Coastal wetlands (incl. mangroves)
Provisioning services	0.01	6.41	0.28	0.34
Food	0.01	0.08	0.27	0.13
Water				0.14
Raw materials	<0.01	2.48	<0.01	0.04
Genetic resources		3.80		<0.01
Medicinal resources				0.03
Ornamental resources		0.05		
Regulating and habitat services	0.01	21.58	3.01	21.69
Climate regulation	0.01	0.14	0.06	0.01
Disturbance moderation		1.95		0.62
Waste treatment		0.01		18.64
Erosion prevention		17.62	2.92	0.45
Nutrient cycling				0.01
Nursery services			0.02	1.22
Genetic diversity	<0.01	1.86	0.02	0.75
Cultural services	0.04	12.52	0.03	0.25
Esthetic information		1.31		
Recreation	0.04	11.07	0.03	0.25
Spiritual experience			<0.01	
Cognitive development		0.13	<0.01	
All services Mean values	0.05	40.51	3.33	22.29
Standard deviation	0.09	76.89	0.58	44.18
Minimum values	0.01	4.23	3.01	0.03
Maximum values	0.19	244.85	4.84	102.10
Number of estimates (de Groot et al. 2012)	N = 14	N = 94	N = 28	N = 139

Based on data from de Groot et al. (2012); adapted from Kite-Powell et al. (2014)

than this, since they make up only a fraction of total coastline, and account for a much greater density of visits.

Table 10.2 summarizes the mean annual ecosystem service value estimates reported by de Groot et al. (2012) and other relevant studies for marine natural resources. These studies include Atkinson et al. (2012), Barbier (2012), Barbier et al. (2011), Brander et al. (2006, 2007), Costanza et al. (2008), Engle (2011), Ghermandi et al. (2008), Grabowski et al. (2012), Rao et al. (2014), Rönnbäck 1999, and Woodward and Wui (2001).

The provisioning service values are dominated by food production services, except for coral reefs, where 95% of estimated value derives from genetic resources (species with potential medical applications, etc.) and other raw materials. The dominant source of regulating/habitat value is erosion control (for coral reefs and

Table 10.2 Mean annual value (in 2014 US$M/km^2) of ecosystem services based on a review of studies from a variety of geographic settings

Habitat/biome	Ecosystem service value, 2014 US$M/km^2/year			
	Provisioning Services	Regulating and habitat services	Cultural services	Total value
Coral reef	6.410	21.100	12.500	40.000
Coastal systems (incl. sea grass)	0.276	3.020	0.035	3.330
Coastal wetlands (incl. mangroves)	0.345	21.700	0.252	22.300
Open ocean	0.012	0.008	0.037	0.057
Beach/shoreline			0.250	0.250

Adapted from Kite-Powell et al. (2014); see text above for sources

coastal systems/sea grasses) and waste treatment (filtering of runoff water) for coastal wetlands. The main source of cultural value is recreational amenities. These are useful starting points for rapid assessment at various locations using benefit transfer concepts; but care must be taken to consider carefully the similarities and differences between study locations and benefit transfer locations before adopting specific ranges of estimates.

Benefit transfer involves the application of non-market valuation models or results developed for one location to another. This method is often used when there are no data on, and insufficient resources to conduct, non-market valuation at the site in question. Benefit transfers comprise the utilization of specific values, such as mean willingness-to-pay (WTP or demand) for ecosystem services or the transfer of functions (estimated for resources in other areas) that can be used to predict WTP on the basis of environmental or socioeconomic characteristics. Boyle and Bergstrom (1992) identify three criteria for benefits transfer: (i) the resources and resource quality conditions should be similar at the two areas; (ii) the socioeconomic characteristics of the relevant populations should be similar in the two areas; and (iii) the specific nonmarket valuation methodologies, models, or estimation techniques used at the studied site should be the same as those that would be applied at the site in question. If these three criteria are not met, a benefits transfer is likely to be biased (this bias is referred to as a “transfer error”). Accepting some level of transfer error may be preferable to the only alternative: assuming that the resource or use at issue has no economic value (Johnston et al. 2014). Where good arguments can be made that criteria (i) and (ii) have been met, it is often sensible to begin with measures of central tendency (means or medians) for ecosystem service values, and to use estimates of confidence intervals, if available, to identify feasible value ranges. As an example, Rosenberger and Loomis (2001) use summary statistics from three decades of studies of recreation in the United States to develop benefit transfer estimates (means and 95% confidence intervals) of consumer surplus per person per day of $32 ± $13 for recreational swimming and $54 ± $10 for recreational fishing (2014 dollars). Additional examples of benefit transfer applications and discussion of limitations can be found in Allen and Loomis (2008), Bergstron and Taylor (2006), Hoehn (2006), Lindhjem and Navrud (2008), and Plummer (2009).

As another example, the value of ocean areas for seafood production from commercial fishing in the New England region of the United States averages about $1200/year/km^2 ($12/year/ha), but ranges widely from near zero to more than $50,000/year/km^2 ($500/year/ha) for specific locations (Kite-Powell et al. 2016). Estimates of ecosystem service value associated with (hypothetical) open ocean aquaculture operations in that region range from $1 million to $100 million/year/km^2 ($10,000 to $1 million/year/ha).

10.3 Public Benefits from Multi-use and Co-location

When a wind farm and aquaculture operation are co-located within the footprint of the wind farm, the two activities together take up less ocean space (habitat space) than they do when they are not co-located. The public benefit from co-location in this case is the avoided opportunity cost associated with ecosystem services that would have been foregone if the aquaculture operation had been located outside the wind farm footprint.

The categories of ecosystem service value most commonly displaced by wind farms and marine aquaculture operations are seafood production and recreational boating and fishing. Both wind farms and aquaculture sites typically designate a buffer zone around the site in which commercial fishing is not permitted. Recreational boating and fishing may be permitted within a wind farm site, and may or may not be compatible with an aquaculture operation, depending on its physical "footprint" in the water column.

Since neither wind farms nor aquaculture operations are usually located in extremely high value ocean areas like coral reefs or mangrove wetlands, as a rule it makes sense to assume that the values at stake will be representative of "Open Ocean" or "coastal ocean" areas as estimated in Tables 10.1 and 10.2. If an aquaculture operation that would displace cultural and provisioning services in any location is sited within a wind farm footprint that does the same, this implies an avoided cost to the public of $0.05 to $0.3/km^2/year—of $500–$3000/ha/year—for the effective footprint of the aquaculture operation.

10.4 Private Benefits from Multi-use and Co-location

Potential private cost savings from co-locating aquaculture operations with wind farms arise from reductions in combined permitting expenses, structural (mooring) and/or site marking costs, costs associated with possible power and/or data links to shore, logistics costs, and/or lease payments. If the aquaculture operation has to bear these costs in their entirety on a site that is separate from the wind farm, and can share costs or services with the wind farm if they are co-located, the resulting avoided cost amounts to a private benefit accruing to the aquaculture operation. This benefit can in practice be shared with the operators of the wind farm.

Permitting expenses and related legal costs arise from the need to conduct studies of fish stocks, benthic resources, cultural resources, endangered species, and other aspects of the proposed site before permits to construct and operate the wind farm or aquaculture operation can be obtained. These studies tend to be site-specific and generally amount to less than 5% of total project start-up and installation costs, or less than 1% of total annualized project costs (Kite-Powell et al. 2003a, b).

If the aquaculture operation can make use of structures (moorings, pilings, etc.) that are installed as part of the wind farm infrastructure (including marker buoys demarking the boundaries of the exclusion zone around the wind farm), or of site-to-shore power cables or data links, this implies reduced installation and maintenance costs for the aquaculture operation. Like permitting costs, these typically represent less than 5% of total annual aquaculture project expenses (Jin et al. 2003; Kite-Powell et al. 2003a, b).

Logistics associated with maintaining the aquaculture infrastructure, bringing seed/fingerlings and feed to the arm site, and transporting harvested product back to shore, typically account for about 5% of the total annual operating cost of an ocean aquaculture operation. The logistics needs of an aquaculture operation tend to be much greater than those of a wind farm, but if the two can share logistics infrastructure and services, this may also represent cost savings on the order of 1% for the aquaculture operation.

The effect on combined leased payments will depend heavily on the lease payment structure imposed by the authorities responsible for permitting wind and seafood farms in the area under consideration. It may be that lease payments are assessed on the basis of output, in which case co-location may not produce any net private savings. If combined lease payments are based strictly on the area occupied by the two facilities, net savings may be achieved by co-locating.

In aggregate, the private cost savings potentially realized by the aquaculture operation from co-locating with the wind farm amount to perhaps 5% of total annualized installation and operating expenses. With cultured seafood farm production valued at $1000–$2000/ton, that is equivalent to about $50–100/ton of production per year. As noted, these private benefits would likely be shared in some fashion between the wind farm and the aquaculture operation, since both must collaborate to realize these benefits.

10.5 Case Study: Mussel Culture and Wind Farms in the Netherlands

In the Dutch debate on multi-use, the emphasis has been on combinations of either bivalve or seaweed production within offshore wind energy parks. From a market perspective, the mussel sector is the most logical choice: there is an existing market for mussels. The market recently has had troubles with the supply of mussel spat due to governmental restriction on mussel spat collection in the Wadden Sea.

Following the identification of potential for bivalve culture in the North Sea, a case-study was carried out to investigate the economic benefits for the co-production mussels and offshore wind energy in the North Sea, summarized here based on information from Sander van den Burg. This case study focused on spatial distribution and examined if vacant space in offshore wind parks can be used for mussels production. It was assumed that mussel production facilities are not physically attached to the wind turbines or their foundations. Within large offshore wind energy farms, the wind turbines are placed in clusters, leaving space between the clusters to avoid wind-free zones. If this vacant space is used for aquaculture, a relatively large and accessible area is created. Within a 1000 MW wind parks, the expected vacant area is 4000 ha (see Fig. 10.3).

This case-study included (i) a simple linear optimization model to analyze how vacant space can be used in the best manner, and (ii) sensitivity analyses to examine the effects of changes in input parameters.

For this exercise, a hypothetical offshore mussel farm was designed in consultation with experts. The proposed mussel farm uses long-lines attached to monopole foundations. The production systems is a long line for mussel spat collection, for first growing and for second growing (in a ration 1:4:16). Size of the system is set at 2.4 km of lines/ha. Based on earlier experiences from a German Case Study (see Chap. 11), expected production is 10,000 kg mussels per km (Buck et al. 2010). The costs for offshore mussel production are estimated using Buck et al. (2010). Fixed costs per ha are estimated at 4255/ha/year, variable costs 1762 €/ha/year. Price for mussels is set at 1.21 €/kg (Buck et al. 2010). Due to the increased production of mussels the price of mussels is expected to decline slightly from 0.95 to 0.94 € kg^{-1}.

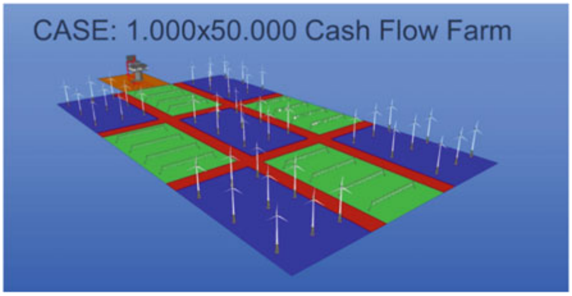


Fig. 10.3 Modelled mussel farm co-located within an offshore wind farm (*Image* Sander van den Burg)

In the model, it is assumed that synergies exist between aquaculture and wind farms, especially related to transport and labor costs. This synergy is set at a relatively low percentage, only expecting benefits from combining transport, operations and maintenance. Thus not the installations, as this would increase (perceived) risks. For wind farms, we set costs for labor and transport (all concerning only O&M) at respectively 759 and 429/ha/year (note that one wind turbine takes up 78 ha (500 m security circle)). The expected synergy is set at 5% of these costs (Lagerveld et al. 2014).

Based on these input parameters, the model shows that the proposed production system for offshore mussel production in wind farms is profitable. Given the estimated costs, price and production, the overall profit to be made is €38 million if the full 4000 ha is allocated to mussel production. This is based on a production of 170,000 tons, revenue of €159 million and a total cost of €121 million.

Another option investigated was ‘to do nothing’ with the vacant space within the wind parks. This option was included to assess the “costs” of single-use. It is important to note that doing nothing means that some of the potential synergy is not made us of. This is calculated at 71 €/ha/year (roughly €5500 per turbine per year).

As offshore cultivation of mussels is not yet an established practice in the North Sea, the input parameters are subject to a certain degree of uncertainty. Sensitivity analysis was therefore performed to shed light on the economic consequences of changes in (i) lower base price for mussels, (ii) lower mussel yield, and (iii) higher cost for mussel production. It was shown that growing mussels is no longer profitable if the price of mussels drops below 0.70 € kg^{-1}, if the production drops to 30.5 tonnes ha^{-1}, if fixed costs increase to 31,000 €, or if transport costs increase to 14,500 € (Fig. 10.4). All sensitivity analyses showed a linear pattern and the results suggests that the model is quite robust as a reduction or increase of the input variables of −25%, −26%, 22% or 25% for price, yield, fixed costs and transport costs respectively still results in a profitable mussel cultivation system.

When it comes to multi-use in the North Sea, the combination of offshore mussel production and wind energy is considered to be the most promising combination. In this case-study, we assessed the economic feasibility of this combination.

Based on the available information, we estimated input parameters. Model results confirm that a good business case is achievable. There is a lot of uncertainty about the data but the sensitivity analysis shows that within the present business case, there is room for higher costs or lower yields.

In this sort of setting, synergies are lost in a single-use scenario. The analysis shows that the achievable synergies are—due to great differences in turnover—relatively high for the aquaculture sector but relatively low for the wind energy sector. A challenge remains to convince the wind energy sector that the synergies are worth the effort and risks.

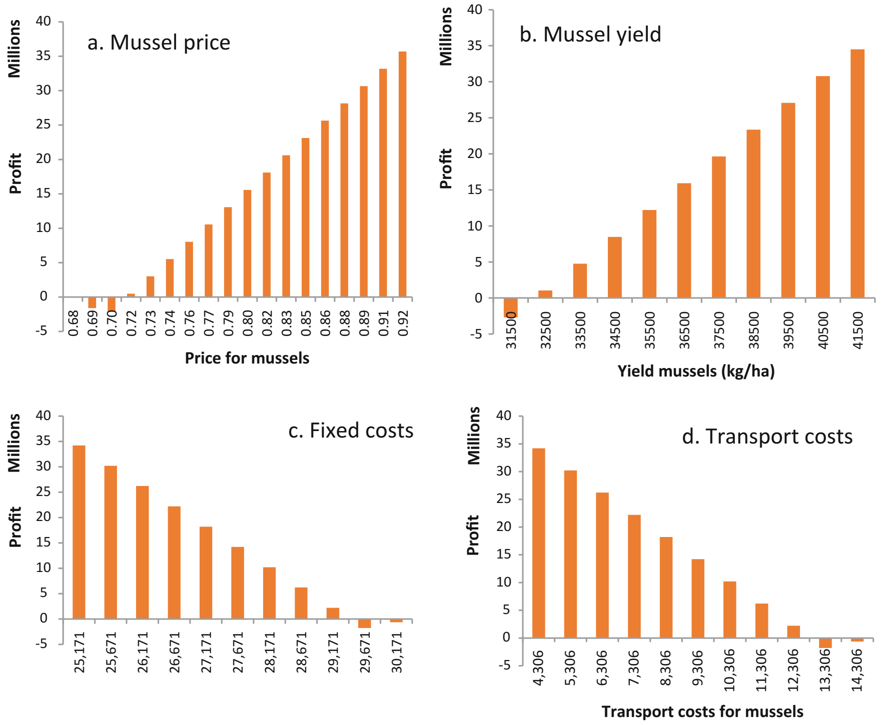


Fig. 10.4 Changes in total profit; sensitivity to changes in price (**a**), yield (**b**), fixed costs (**c**) and transport costs (**d**)

10.6 Conclusions

Co-locating aquaculture operations and wind farms can produce both public and private benefits (cost savings). The public benefits arise from the fact that an aquaculture operation co-located within the boundaries of a wind farm does not negatively affect the ecosystem services derived from the ocean area it would otherwise have occupied. The private benefits are cost savings that arise from shared permitting, infrastructure, and logistics efforts and systems.

The economic value associated with these benefits depends on the scale, location, and nature of the co-located ventures and the natural resources they affect. For locations in open ocean and relatively low-value coastal waters that are candidates for wind farm or aquaculture sites in most countries, the public benefit is likely to be on the order of $500–$3000/year/ha of area occupied by the aquaculture operation, and the private benefits are likely to be less than $50–100/ton of aquaculture operation output.

Because co-location can offer public benefits, it makes sense for local, regional, and national regulation of the siting of energy (e.g. wind farm), seafood production (e.g. aquaculture), and similar ocean uses should encourage developers to consider co-locating operations. This can take the form, for example, of more favorable lease terms for co-located facilities. Co-location is not likely to change the fundamental economics of ocean spatial use, but at the margins, it can make economic activities in the ocean more efficient.

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