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Fishermen facing headwinds

A quantitative approach to evaluating fishing grounds and measuring the impact of offshore wind on the commercial fishing industry

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Abstract

In this thesis, we investigate the impact of developing offshore wind farms in Træna on the local community and the fleet operating in the respective areas. In particular, we evaluate the catch value within each offshore wind farm area, and measure the following externalities, specifically detours caused by spatial occupation.

We develop a model that locates catch value using position data and apply the distribution of this catch value to data without coordinates to create the best possible value estimate of specific areas, as well as using the position data to estimate detours and the consequent externalities of the detours. Our findings suggest that the negative impact of offshore wind on the commercial fishing industry, compared to the uncertainties surrounding future profitability of offshore wind, advocate that the decision regarding development of offshore wind in Træna should be made in coexistence with fishermen and that their opinions should weigh heavily.

Acronyms and terms

AIS

Automatic identification system

Dockdf

Landing dock areas data frame, geographic data frame

DoF

Directory of Fisheries - Fiskeridirektoratet

GHG

Green house gasses

Heatmap

A heatmap is a map that uses coordinates. Each coordinate has value, e.g. catch value or catch weight. The higher concentration of value in a area with coordinates, the "warmer the color". Heatmaps are an efficient tool to visualise in what areas a certain value is concentrated

Landing (used as verb)

An action where the fishermen delivers/sells the catch to a establishment

Landing notes

Landing notes - Sluttseddler / Landingsseddler

LCOE

The levelised cost of energy (LCOE), or levelised cost of electricity, is a figure that shows the average total cost for the kilowatt hours produced from a power plant over its lifetime

MFAdf

Main catch areas data frame, geographic data frame

NVE

The Norwegian Water Resources and Energy Directorate - Norges Vassdrags- og Energidirektorat

ODE

The Norwegian Ministry of Petroleum and Energy - Olje- og energidepartementet

OWAdf

Offshore wind areas, geographic data frame

VMS

Vessel monitoring system

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1 Introduction

1.1 Motivation and purpose

Fishing has played an important role in Norwegian history since the early Stone Age (Hallenstvedt and Dørum, 2020). In Europe, Norway is the largest fishing nation, and ranked as number nine in the official World ranking (Regjeringen, 2017). The commercial fishing industry has through history been a cornerstone in the Norwegian economy, and many would argue it is of importance to implement actions in order to keep it that way.

This summer, The Norwegian Government made it possible submitting license applications for developing offshore wind farms in Norway. From the 1st of January 2021, two areas on the Norwegian continental shelf will be opened for offshore wind: *Utsira Nord* and *Sørlige Nordsjø II* (Regjeringen, 2020b). Renewable energy is an important contribution to reach Norway's climate goal of reducing green house gas (GHG) emissions by 50-55% within 2030 (Regjeringen, 2020a). However, establishing offshore wind farms might be harmful to the life at sea as well as affecting local fishermen, and this thesis aims to investigate how the local community and their fishermen will be affected if offshore wind farms are established in Træna.

The Norwegian Directory of Fisheries (DoF) recently stated that the usual way of investigating issues related to fishing activity and the increasing competition for spatial areas at sea, relies heavily on qualitative research, which is often time consuming and resource intensive (Directory of Fisheries, 2020c). This statement motivated us to investigate the possibility of analysing spatial area issues at sea by a purely quantitative approach.

We have created a model that connects position data to landing notes (sluttseddler) in order to trace catch value down to specific coordinates. Our model is able to calculate the total detour that will occur if one or more areas are occupied by an offshore wind farm, based on historical position data. As of method, we have used the results and distribution from our model as a sample to estimate the locations of the value for the landing notes belonging to vessels without position tracking. The key measures computed using our methodology is the total estimated value of fishing areas and the total detour caused by occupying spatial areas.

The data used in our model, consists of position data for all Norwegian fishing vessels using tracking systems, fishing in the time period between 2016 and 2019. We have also used the electronic logbooks from all Norwegian vessels larger than 15 metres from the time period 2016 to 2019. All this data is confidential and is delivered from the archives of DoF and The Norwegian Coastal Administration (Kystverket). The landing notes are public data, and are retrieved from the website belonging to DoF. Additionally, we used geographic data in order to determine geographic areas important for our investigation.

We find that the fishing grounds within Trænafjorden Sør and Nord are moderately essential for the local population, whereas approximately 9% of total catch value in their respective catch areas is caught within the offshore wind areas. Trænafjorden Sør entails the greatest impact on local fishermen, whereas the detours caused by occupying spatial area in this fishing ground are estimated to entail up to 2000 labour hours in loss of opportunity costs over a period of three years. Subsequently, these detours may also lead to increased competition in local fishing grounds, which consequently entails reduced profits for the fishermen. We also detect worst case scenarios by developing Træna Vest and Trænafjorden Sør with potential fatal consequences for the local fishermen. This possibility of inflicting a well functioning and sustainable industry, raises questions towards the future profitability of offshore wind farms and on what terms they are to be developed.

1.2 Research question

The purpose of this thesis was to create a generic, quantitative model for measuring the economic consequences for fishing vessels in the scenario of the development of offshore wind farms in the areas where the vessels operate. Since the model is generic, every area can be analysed if the input data for the required area and time period is provided. By developing and applying a model of this kind, we were able to investigate the following research question:

What are the economic consequences of establishing offshore wind farms in Træna for the local community and the fleet operating in the respective areas?

Investigating the main research question, we also aimed to answer the following sub research question:

What are the additional detours fishermen will have to travel if offshore wind farms are established in Træna?

The thesis is structured as follows: First, we present the background, including a review of the Norwegian fisheries, the Norwegian renewable energy industry and the research areas. Second, we present relevant literature with regards to externalities caused by wind farms and co-existence between fishermen and offshore wind farms. Thereafter, we present the different types of data used for the model, before we present the methodology. Furthermore, we present the results and then discuss the results in light of the research question. Finally, we evaluate the methodology and present the conclusion.

2 Background

2.1 A brief recap of the Norwegian fishing industry

2.1.1 The importance of the fishing industry to the Norwegian economy

The fishing industry plays an important role for the Norwegian economy. In 2019, fisheries accounted for 6.5% of Norway's total export excluding gas and oil, and the total value of the exported fish amounted to NOK 30.8 Bn (Statistics Norway, 2020c) (Norges Sjømatråd, 2020).

In 2019, Norwegian fishermen caught 2.5M tonnes of fish, or ~460kg per inhabitant (Statistics Norway, 2020e). The amount of fish caught has been relatively stable over the last 50 years with a dip in the 80s, partly due to governmental regulation as the cod was at the brink of extinction (Statistics Norway, 2018) (Statistics Norway, 2020a).

The productivity of Norwegian fishermen has almost tripled during the last 40 years. In 2019 there were ~11K registered fishermen in Norway distributed on ~6K vessels, compared to ~34K fishermen distributed on ~26K vessels in 1979. However, the quantity of fish caught in 2019 compared to 1979 is quite similar (Statistics Norway, 2020b) (Statistics Norway, 2020a). The reason for the increased productivity is larger vessels and improved technology (Statistics Norway, 2018). When the productivity increases, the opportunity costs for a fisherman's labour hour does as well, thus one can argue that the costs of delay for a fishermen today is much larger than in the 70s.

2.1.2 Tracking of fishing activity

Having a detailed overview of where, what and the quantity of fish caught is important to protect the life at sea, the interests of fishermen, and make sure that the fishing industry adhere to Norwegian regulations. The following paragraphs will elaborate on which data that is currently available on fishing activity and how the DoF currently works to develop a methodology which makes it less labour intensive to obtain an overview of important fishing grounds.

2.1.2.1 Landing notes

The fishing vessels and the ports receiving the fish are, according to *The Landing notes regulations* (landing regulations), responsible for weighing the catch and sending a *Landing note* to the DoF with information about the catch, including the main areas where the fish was caught (Lovdata, 2020). However, the reporting of the catch area where the fish was caught is quite imprecise, and in many incidences the fishermen report the locations where they usually fish instead of the actual catch area of the fishing activity (Directorate of Fisheries, 2018).

2.1.2.2 Position reporting of fishing activity

According to §§ 7 and 8 of *The Law of Position and Electronic Reporting for Norwegian Fishermen* all vessels larger than or equal to 15 metres must report its position to the DoF (ERS-forskriften, 2010). Position reporting is also mandatory for vessels equal to or larger than 12 metres fishing more than 4 nautical miles from the baseline in Skagerak. According to § 8, the position of the vessel should be reported automatically every 10-60min depending on the size of the vessel.

Position data makes it easier to get a precise overview of areas that are important spawning grounds and fishing areas. Due to the current jurisdiction described in the previous paragraph, the data availability of position data is good for large vessels and vessels fishing >4 nautical miles from the Skagerak baseline. However, the data quality is poor for smaller fishing vessels and vessels close to the coast.

In 2018, the DoF suggested to require all fishing vessels to report their position to the Directorate from 2022. The rationale was that improved data quality on smaller vessels would allow for a better understanding of coastal fishing patterns, thus improving protection of the life at sea and the interests of fishermen (Directorate of Fisheries, 2018).

2.1.2.3 Coastal data (kystnære fiskeridata)

In the 1980s, the DoF started to capture *Coastal data* covering important spawning grounds, fishing areas and fishing tools etc. The data is based on interviews with fishermen and is used to classify the importance of different fishing areas. However, the interviews are time consuming and the DoF is currently working on how to couple landing notes with *position data* to obtain a more precise and less labour intensive way to map the most important fishing areas (Directorate of Fisheries, 2020).

2.1.3 Requirements for fishing activity

The main requirement of fishing activity related to this thesis is the space required to perform different types of activities. The amount of space needed is rather individual and depends on a range of variables. To exemplify, a purse seine that is 800 meters long, requires a lot of space, both in sense of manoeuvring and the gear itself(Johnsen, 2020), and on the other hand, fishing with single hook gear requires less space. As of space requirements in general, large vessels equipped with seines or trawls require large unoccupied areas, while smaller vessels geared with nets and hooks are able to conduct fishing activities in areas with less space and some degree of obstacles (Directorate of Fisheries, 2012).

Fishing vessels also have different limitations to the range in form of fuel capacity and their ability to handle severe weather conditions and large waves. Thus, smaller vessels require to reach fishing grounds close to their ports, while larger vessels are able to travel far out and conduct fishing activity for several weeks (Directorate of Fisheries, 2012).

2.2 Norwegian renewable energy production

Norway is the country in Europe with the highest share of energy from renewable resources. In 2020 hydro power accounted for 90% of total production capacity, whereas wind power accounted for 7.2% (Norwegian Ministry of Petroleum and Energy, 2020). On average, 10% of the power production has been exported over the previous 30 years, and this has accounted for ~ 0.3% of total Norwegian export measured in prices as of 2020 (Vista Analyse, 2020). Of the total amount of energy produced, 30% was consumed by both power-intensive industry and Norwegian households (Holstad et al., 2019).

This summer, The Ministry of Petroleum and Energy opened the first areas for offshore wind power on the Norwegian continental shelf: *Utsira Nord* outside of Haugesund and *Sørlige Nordsjø II* outside of Kristiansand (Ministry of Petroleum and Energy, 2020). Currently the *levelised cost of energy* (LCOE) for offshore wind power (0.7 - 1 NOK/kWh) is not competitive with, for instance, Norwegian hydro power (0.33 NOK/kWh), but in the future, offshore wind production might grow to become an important source of power for Norway (Olsen, 2015) (enerWE, 2019). Firstly, because Norway is one of the countries in Europe with the best wind conditions for wind farms (NVE, 2019b). Secondly, Norway has leading expertise within maritime technology (Norsk Olje og Gass, 2020). Thirdly, large companies with extensive offshore experience are willing to invest in the technology, such as Equinor which currently works on developing world's first oil platforms powered by offshore wind (Equinor, 2020).

2.2.1 Energy production versus nature conservation

In this section, we will briefly discuss the interest of conflict between development of energy production and conservation of local nature and natural resources in Norway.

There is an increasing need for energy in Norway, and The Norwegian Water Resources and Energy Directorate (NVE) estimates that Norway will need 18% more energy in 2035 compared to 2016 (Spilde et al., 2018). However, developing new energy resources whether it is wind, sun or hydro power may sometimes be in conflict with interests to preserve the environment and local culture.

The Alta controversy is probably the conflict between energy and nature preservation that have received most media publicity in recent Norwegian history. The Alta Controversy lasted from 1968 to 1982 and concerned the establishment of a hydro power plant in an crucial area for the Sámi people and their culture in the former county Finnmark. In addition to being important to the Sámi people, the watercourse was of unique importance to the agriculture and nature in Alta and the Norwegian cultural heritage. However, after several years of civil disobedience, hunger strikes in front of the Parliament and trials, the Supreme Court declared that the development of the hydro power plant was in line with Norwegian law (Berg-Nordlie and Tvedt, 2019). The Alta controversy is believed to have strengthened and emphasised the importance of taking the environment into account in subsequent cases of developing power plants (NVE, 2018).

2.2.1.1 Types of offshore wind turbines

There are two types of offshore wind turbines: Bottom-fixed and floating installations. Today, over 23 000 megawatt (MW) offshore wind is installed in the world. 55 MW, or 0.24%, of the total is floating installations, and the rest is bottom-fixed (Østenby, 2019). All the floating installations are built as demonstration projects. Equinor's project in the Tampen-area, *Hywind Tampen*, will become the world's largest wind farm consisting of floating installations. This farm alone will have an installed capacity of 88 MW, and will supply the oil rigs, *Snorre* and *Gullfaks* with electricity (Equinor, 2019).

With the technology we have today, the installation of bottom-fixed turbines require sea levels shallower than 60 metres. At deeper waters, the only current solution is floating turbines. This limitation regarding bottom-fixed turbines is under continuous research and development, which makes the scenario of bottom-fixed turbines at deeper sea levels within the upcoming years feasible (Østenby, 2019).

At this point, offshore wind farms are not considered to be profitable (Viseth, 2019). Britain is the leading nation in offshore wind, and according to a study done at the Imperial College London, offshore wind farms may be profitable within about 2025 if the offshore wind costs continue to drop, and the power price continues to rise (Hovland, 2020). However, at what time the Norwegian offshore wind will be profitable is difficult to predict.

In the following paragraphs we will elaborate on the potential conflict of interests between the development of offshore wind farms, and the commercial fishing industry.

2.2.1.2 Coexistence between the commercial fishing industry and offshore wind

Norway has all the important prerequisites in order to become a new leading country in the offshore wind industry (NVE, 2019b). In the future, if it is decided to invest more in offshore wind power, Norway could potentially export significant amounts of renewable energy produced on the Norwegian continental shelf to various countries in Europe. In 2018, onshore wind power accounted for ~2.6% of the total energy production in Norway. In 2019, it rose to ~4.1%, and the increase seems to be on a continuous path (Holstad et al., 2019) (Øvrebø, 2020). But the establishment of offshore wind farms might have a significant impact on nature, culture and local industries.

The Marine Energy Act (Havenergiloven) (Lovdata, 2010) regulates development of offshore renewable energy resources. According to paragraph § 9-1 financial loss experienced by fishermen caused by energy production should be compensated. However, it is not described how the compensation should be determined.

Offshore wind might be harmful to marine mammals, fish and spawning grounds, and thus to the commercial fishing industry (Directorate of Fisheries, 2012). Offshore wind farms damage the seabed when they are mounted to the ground and the cables connecting the wind mills might attract alien species that not naturally live in the area. The cables do also create electromagnetic signals that might potentially have an impact on the fish's ability to orientate (Institue of Marine Research, 2020). Lastly, the anthropogenic noise from wind mills might interfere with fish's ability to communicate (Jong et al., 2017).

The size of safety zones around offshore wind farms and what sort of fishing activities that are allowed depend on the the location of the wind farm. Wind turbines might interfere vessel's navigation system if they are too close to the farm. Secondly, the wind mills will pose a large threat in case of engine failure. During winter times the blades of the wind mills might be covered in ice, resulting in a formation of huge ice blocks with the potential of being launched, causing a huge risk to nearby vessels (Directorate of Fisheries, 2012).

Offshore wind farms have to be located on relatively shallow water, and the installation depth of the offshore wind farms is positively correlated with the development and maintenance costs (NVE, 2019a). Areas close to the harbour are preferred development locations of offshore wind as this reduces transportation cost. However, areas close to the harbour with shallow waters are often also efficient fishing grounds for fishermen fishing *demersal fish*, fish living close to the seabed (Directorate of Fisheries, 2012). Fishing close to the harbour is often essential for smaller vessels with limited range. This requirement of shallow waters, both for the installation of offshore wind and as fishing grounds for smaller vessels, entails a competition for spatial areas close to the harbour.

2.3 Offshore wind in Træna

In 2010, NVE recommended to conduct an investigation including two locations in Træna and 13 locations and their suitability for development of offshore wind farms. The two locations in Træna were referred to as *Træna Vest* and *Trænafjorden - Selvær* (NVE, 2010). DoF took part in this investigation and in the final report published in 2012, DoF advised the government to not develop offshore wind farms in Træna Vest as the the consequences for local nature and wildlife would be fatal (Directorate of Fisheries, 2012). Trænafjorden - Selvær was classified moderate suitable for development of offshore wind, taking into account the consequences that would entail the fishermen. However, in a further hearing conducted by Nordland County Council (Nordland Fylkeskommune, 2013), it was a mistake to not investigate Trænafjorden - Selvær as two different locations, because in their opinion the South area of this location would entail severe consequences for the local fishermen, while the North area would involve less consequences. Taking this into account, we have decided to investigate Trænafjorden - Selvær as two separate areas: *Trænafjorden Sør* and *Trænafjorden Nord*.

In the following section, we will briefly describe the local community of Træna and the three possible locations for offshore wind development: Træna Vest, Trænafjorden Sør and Trænafjorden Nord.

2.3.1 General information about Træna

Træna is located at the Helgeland Coast in Nordland county and is visualised as a black circle in figure 2.1. ~450 people live in Træna (Trænafjorden - Selvær and Gimsø), whereas 60 people (~13%) work in the commercial fishing industry (NordNorsk Reiseliv AS, 2020). Træna is the oldest fishing village in Norway, and there are archaeological findings of fishing tools older than 9000 years (NRK, 2020).

Figure 2.1: The black circle is Træna's location in Norway, southwest of Bodø. (Source: DoF map services)

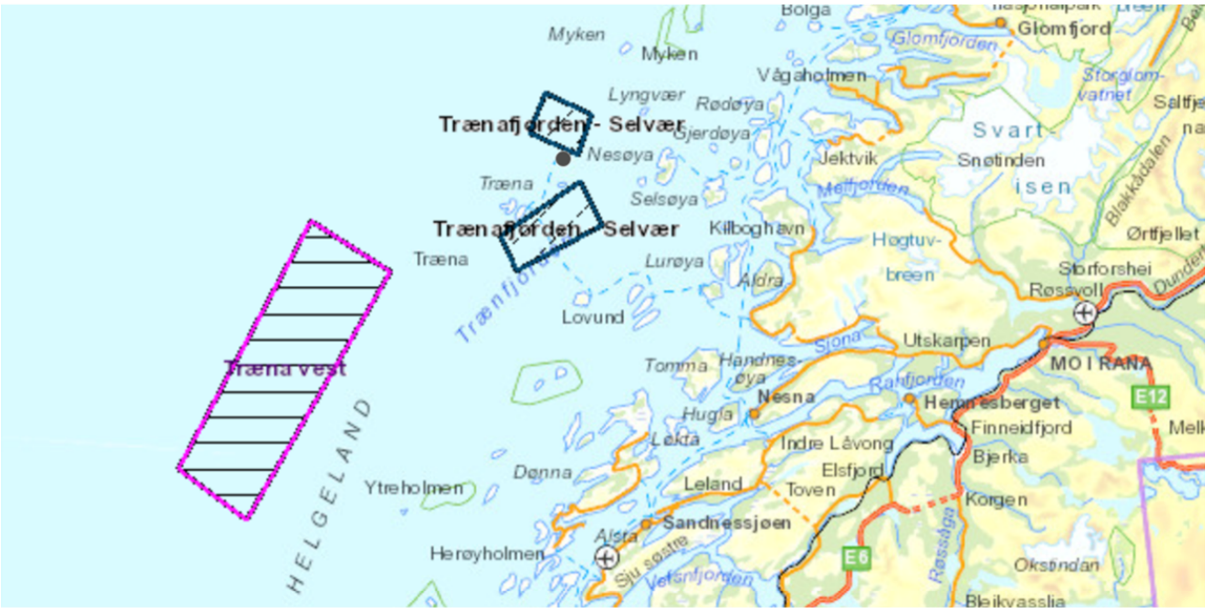


Figure 2.2: All research areas and their locations in relation to each other. (Source: DoF map services)

2.3.2 Træna Vest

Træna Vest (pink rectangle in figure 2.2) is a large area located west of Træna municipality. The depth in these waters is reported to be between 181 and 352 meters. This signals that this area is considered for floating wind turbines. The average wind speed here is measured to be 9.8 m/s. Træna Vest is located about 45 km from the Nordland coast, so no bird activity has been registered in the area (Berg et al., 2012). But there is a lot of shipping traffic that sails through here. The area between Sandnessjøen and the Norne field consists of a lot of traffic, and the entrance to the industrial area on Helgeland also goes through Træna Vest. In addition to large fishing vessels such as trawlers, there are also many offshore supply vessels and similar ships here. According to the report developed by NVE (2012) shipping and fishing are the topics that will have the greatest consequences if a wind farm is to be built here.

2.3.3 Trænafjorden Sør

Trænafjorden Sør, is the furthest south area of the two areas marked in figure 2.3. This location is a popular passage for large vessels and is in fact recognised as the busiest location of all study locations investigated by NVE (Berg et al., 2012).

In addition to a lot of ship traffic, there is also a lot of fishing activity conducted by local fishermen from Træna. A possible development of bottom-fixed wind turbines here will also be visible for the inhabitants in Træna, especially the ones located at Husøy. According to a hearing conducted by Nordland county council (Nordland fylkesting) (2013), these factors signals that Trænafjorden Sør is not well suited for the development of an offshore wind farm.

Figure 2.3: Trænafjorden Nord and Trænafjorden Sør. On the map from the Norwegian Direcotrate of Fisheries, there are two areas (the blue squares) called "Trænafjorden - Selvær". The square located furthest north is Trænafjorden Nord. The other square is Trænafjorden Sør. (Source: DoF map services)

2.3.4 Trænafjorden Nord

Trænafjorden Nord is located furthest north of the two areas marked in figure 2.3 and the waters surrounding this location is relatively shallow. Trænafjorden Nord is not a popular passage for vessels and there is limited vessel traffic in this location. Trænafjorden Nord is a location that is considered to entail small consequences on the local community and fishermen if a wind farm is developed in this area. The two factors that have the greatest consequences in the event of a development of an offshore wind farm are birds and marine mammals, with a grade of 3 and 2 out of 5, respectively (Nordland Fylkeskommune, 2013).

3 Literature Review

There is an increasing interest regarding investing in and the development of offshore wind farms. However, in the perspective of energy development history, the development of offshore wind and its consequences on the commercial fishing industry is still rather unexplored, and the literature related to the subject is limited. We have divided the literature into two main categories: (1) Impact assessments conducted on behalf of intended development of offshore wind, and (2) reports that analyse the consequences occurred post developing wind farms.

The first main literature category involves the most similarities to our thesis, as we aim to investigate consequences that might occur from a development that has not yet been initiated. Literature we have included from category one is the impact assessment conducted by DoF (2012), where we highlight the methodology approach, its limitations and the main findings. In the second main category of the literature, we have included two reports conducted in hindsight of offshore wind farm development near the British coastline. These reports provide an overview of discovered externalities caused by offshore wind, and results of coexistence between the offshore wind industry and the commercial fishing industry.

3.1 Category 1: Impact assessment of the offshore wind on the commercial fishing industry

In 2010, NVE conducted an assessment to detect and analyse locations suitable for the development of offshore wind farms (Drivenes et al., 2010). This assessment resulted in *The Offshore Wind Report* (Havvindsrapporten), where 15 potential locations were located and investigated. After submitting The Offshore Wind Report, NVE was commissioned by The Norwegian Ministry of Petroleum and Energy (OED) to carry out an impact assessment of these 15 locations. There were several impact factors to take into account, including the impact on fisheries. DoF was commissioned to investigate the impact of offshore wind on commercial fisheries in the 15 locations, and the results from this investigation are submitted in the *Impact assessment DoF* (Fagrapport til strategisk konsekvensutredning av fornybar energiproduksjon til havs) (Directorate of Fisheries, 2012).

In order to assess the impact in each location, DoF categorised and assigned the 15 locations in five categories, where category five indicated the highest level of impact. Which category each location was assigned to, depended on three factors and their respective scores (Directorate of Fisheries, 2012).

The first factor was the total catch value within each catch location nearby or surrounding the intended locations of offshore wind farms. The data used to assess total catch value, was landing notes retrieved from 2001 to 2010. Within this factor, each location could be assigned a score between one and three, where three indicated a significant amount of catch value. The second factor included, was the number of vessels under 15 metres operating within the intended offshore wind area. The rationale behind this factor was that the offshore wind areas were located close to the harbour and the smaller vessels operating there are exposed and vulnerable as they do not have the opportunity to fish further out in the sea. Within this factor, each location could be assigned a score between one and three, where three indicated a significant concentration of vessels under 15 metres. The third factor was based on the commercial fishing association and their professional assessment. If they believed the score from factor one and two were underrated for a given location, they were allowed to add a score worth one point to this location (Directorate of Fisheries, 2012).

As of data to provide additional information, DoF used position data and coastal data. The position data was used to visualise the concentration of fishing activity within a location, based on a speed filter five knots and below. The coastal data, which often include locals and their knowledge regarding fishing and spawning grounds in a location, was used to obtain an overview of the concentration of fishing activity, where no position data was available (Directorate of Fisheries, 2012).

The three factors and their respective intended offshore wind farm locations were summarised, and each location was placed within one of the five categories, where category five entailed large negative consequences towards the fisheries operating within the location.Both Træna Vest and Trænafjorden – Selvær were assigned category five. DoF decided to evaluate Trænafjorden – Selvær as one area, instead of two separate locations. The rationale of this, was that their catch statistics were too inaccurate to differentiate them from each other. This issue applied to many of the areas, because the intended offshore wind farm areas mostly only occupied a fraction of the catch areas, and DoF did not have a method to valuate areas at such a high level of detail (Directorate of Fisheries, 2012).

DoF concluded the report by emphasising that coexistence between the energy industries and the commercial fishing industry is of high importance when sharing resources and spatial areas at sea. They also concluded that the development of offshore wind farms assigned category five, would induce major negative consequences for the commercial fishing industry and their recommendation was not to establish offshore wind farms in these locations (Directorate of Fisheries, 2012).

3.2 Category 2: A qualitative approach of mapping externalities

Mackinson et al. (2006) wanted to address a current policy need in Defra (Department for Environment, Food and Rural Affairs) by providing scientifically robust findings to help understanding the effects on the commercial fishing industry caused by the developed offshore wind farms.

In order to execute this, Mackinson et al. conducted face-to-face interviews with fishermen, questionnaires and a workshop aimed to increase knowledge sharing between government, wind farm developers and the commercial fishing industry. Through these methods, Mackinson et al. collected both quantitative and qualitative research to analyse and summarise valuable information in order to make an overview of the impacts caused by offshore wind farms in the nearby of a fishing area.

The main limitation in the methodology, assessed by Mackinson et al., was the poor response from the fishermen, and consequently a small data sample to draw results and conclusions from. However, the findings are important to raise awareness and stimulate further discussion. Additionally, they detect a general limitation to their research regarding the lack of detailed coastal data. They argue that obtaining a method to collect and apply such data, would provide valuable contextual information to all sea users.

The main findings of Mackinson et al. was a detailed mapping of externalities brought on on the commercial fishing industry by offshore wind farms. The externalities were weighted based on the number of times they were mentioned and the number of fishermen involved in the interview. The most profound externalities detected are visualised in table 3.1.

Table 3.1: Externalities categorised in two groups weighted by frequency mentioned by fishers (Mackinson et al., 2006)

Externality Category	Externality	Weight points
Effects on fishing activities	*Increased time steaming instead of fishing*	*40*
Effects on fishing activities	*Greater competition on remaining grounds*	*39*
Effects on fishing activities	*Reduced fishing area*	*25*
Effects on fishing activities	*Increased costs*	*20*
Effects on fishing activities	*Reduced catch*	*20*
Socio-economic effects	*Loss of profit*	*27*
Socio-economic effects	*Reduced income in local economy*	*28*
Socio-economic effects	*People leaving industry*	*10*

3.3 Category 2: Change in fishing patterns as a result of the development of offshore wind farms

Gray, Stromberg, and Rodmell (2016) aimed to investigate the extent of fishing activities before and after the development of offshore wind farms around different estuaries in Great Britain. They wanted to conduct an evidence-based method to investigate if the changes in fishing activity were connected to the development of offshore wind farms. They also wanted to conduct case studies showing best practice for how to achieve satisfying co-existence between the commercial fishing industry and offshore wind farms.

Gray, Stromberg, and Rodmell (2016) approached their studies by using a matrix method which was based on the combination of the strength of evidence and the level of agreement to a questionnaire given to fishermen, fisheries managers and offshore wind developers. This was their primary data. Their secondary data was positioning data from fishing vessels and collecting of data showing fish landings and fishing activities.

Through the quantitative analysis using position data, Gray, Stromberg, and Rodmell (2016) concluded a decrease of fishing activity within the areas offshore wind had been developed. Through the qualitative analysis and matrix tables, they concluded that fishermen strove coexisting with the offshore wind industry and that most fisherman effected, reported dissatisfaction regarding how the coexistence was carried out.

3.4 Implications for our study

In the literature related to our thesis, we detected a recurring limitation within all the reports reviewed. This limitation was related to the the narrow and inaccessible basis for analysing coastal fishing activity. The Directorate of Fisheries (2012) estimated fishing activity close to the harbour, by using landing notes and its reported catch location as a way to locate value. The catch locations are large spatial areas, and the accuracy and level of detail are thus limited. Mackinson et al. (2006) aimed to measure coastal fishing activity by a qualitative approach, that turned out to be a time consuming approach, resulting in a small sample and limited credibility. The report conducted by Gray, Stromberg, and Rodmell (2016), highlighted the difficulties arising when offshore wind farms and fishermen have to coexist and share the spatial areas at sea.

Taking the literature review and its current limitations to account, our thesis aims to develop a methodology that extend the possibility of analysing coastal fishing activity, providing a less time consuming and more accurate approach.

4 Data

In order to create a model that assess value to specific coordinates and allows for analysis linked to offshore wind, we found it necessary to include data regarding fishing activity, position data of fishing vessels, a profitability report conducted by DoF and spatial coordinates data to areas of interest.

4.1 Landing notes (Sluttseddler)

The landing notes are the core documents in the administration of Norwegian fishing, and among other things, the notes lay the foundation for resource accounting, research, regulations and confiscation of overfished quota (Directory of Fisheries, 2017). This data is available to the public and is downloaded from the web pages of DoF. In our model, we aim to merge these notes with respective position data and the landing notes are providing output such as catch value, fishing gear, fish species, time of landing and vessel ID. The full list of variables is located in table A0.1, A0.2 and A0.3.

4.2 Position data

As of today, fishing vessels larger than or equal to 15 meters, are according to regulations required to continuously log and submit their position and catch data during fishing (Lovdata, 2009). This way of logging data is referred to as *Electronic recording and reporting system* (ERS), and the main components applied to our model from this system is the *Electronic logbook* and *Vessel monitoring system* data (VMS).

Vessels smaller than 15 meters are not required to monitor fishing activity and are not obliged to use tracking equipment (Lovdata, 2009). However, most fishing vessels between 11 and 15 metres are equipped with *Automatic identification system* (AIS) trackers, that provides information regarding the whereabouts of the fishing vessel.

Further on, we will describe the position data sources Electronic logbook, VMS and AIS.

4.2.1 Electronic logbook

DoF has provided a csv file that contains electronic logbooks to all Norwegian fishing vessels, fishing in the period between 2017 and 2019. The relevant variables used from this data set are described in table 4.1.

Table 4.1: Relevant variables in the Electronic logbook

Variable	**Call signal**	Start time	Stop time	Fishing gear	Fish species (code)	Fish species	Round Weight
Description	*ID connected to vessel*	*Start time for when the fishing vessel deploys the fishing gear in the water*	*Stop time for when the fishing vessel pulls in the fishing gear*	*Type of fishing gear*	*Type of fishing gear (code)*	*Type of fish*	*Temporary reported weight of the catch*

In the electronic logbook, fishermen are required to log the time when the fishing gear is deployed and when it is pulled up, as well as the type of gear and the species of the catch. This allows for a more accurate way to merge the correct position data with their respective landing notes and makes the electronic logbook an important intermediary between VMS data and landing notes.

4.2.2 Vessel monitoring system

According to the *European Commission* (2016), VMS is a satellite-based tracking system which at regular intervals provides data to the fisheries authorities on the location, course and speed of fishing vessels. In cooperation with DoF and The Norwegian Coastal Administration, we were assigned a csv file containing VMS data to all Norwegian fishing vessels, equal to or larger than 15 metres, fishing in the period between 2016 and 2019 within the spatial area drawn in figure 4.1. The relevant variables used from this data set are described in table 4.2.

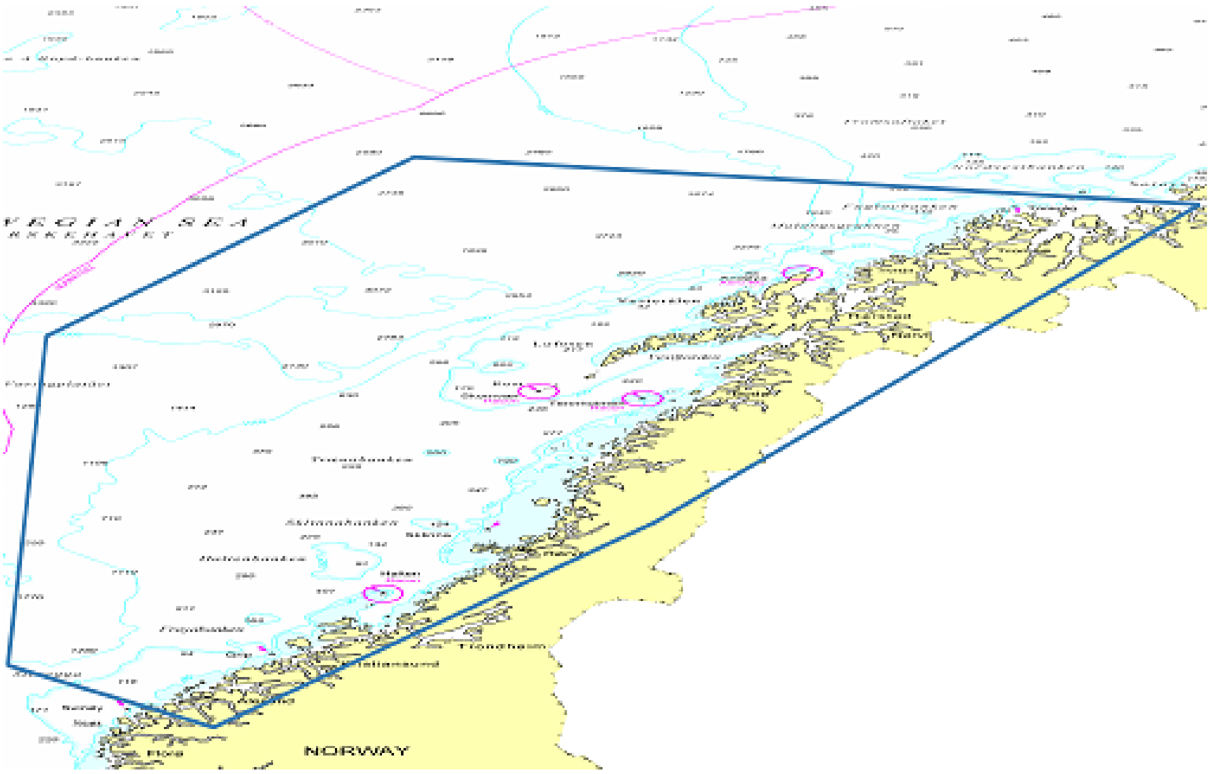


Figure 4.1: Area of VMS data

Table 4.2: Relevant variables in VMS data

Variable	Call signal	Timestamp	Longitude	Latitude	SOG
Description	*ID connected to vessel*	*Date/time assigned to location*	*Longitude coordinates*	*Latitude corrdinates*	*Vessel speed at that given moment*

4.2.3 Automatic identification system

According to *MarineTraffic* (2018), AIS is an automated, autonomous tracking system used in the maritime world for the exchange of navigational information between terminals equipped with AIS. In cooperation with DoF and The Norwegian Coastal Administration, we were assigned a csv file containing AIS data to all Norwegian fishing vessels, smaller than 15 metres, fishing in the period between 2016 and 2019 within the spatial area drawn in figure 4.1. The relevant variables from the AIS data set, are the same as the ones in the VMS data set, and are described in table 4.2.

4.3 Profitability report (Lønnsomhetsrapport 2018)

This is an annual report developed by The DoF to analyse the productivity of the fishing fleet. The measure we used from this report was the average crew per vessel, where the vessels were categorised in groups (Directory of Fisheries, 2018).

4.4 Geometric location of spatial areas of interest

To perform calculations and functions that, for instance, indicate if a coordinate is inside or outside a spatial are, we needed data containing coordinates of these areas of interest. To retrieve such data, we downloaded so-called *shapefiles*, which are files for storing the geometric location and attribute information of geographic features (Esri, 2020). The spatial areas of interest were:

- **Offshore wind areas (OWAdf):** Coordinates that indicate where the three offshore wind areas are located. Shapefile is downloaded from the map services developed by from The Norwegian Water Resources and Energy Directorate (2020).
- **Main catch areas (MCAdf):** Coordinates of the main fishing areas developed and used by DoF. Shapefile is downloaded from the map services developed by Dof (2020).
- **Docks used by fishing vessels (Dockdf):** Coordinates of the docks used by fishing vessels operating in Norway. Shapefile is downloaded from the map services developed by DoF (2020).

5 Methodology

5.1 Methodological approach

We have created a model that connects position data to landing notes in order to trace catch value down to a specific coordinate. Including the ability of valuating locations, the model is able to calculate the total detour that will occur if one or more areas are occupied by an offshore wind farm based on historical position data. Since we connect landing notes to coordinates, the model will also detect whether the implied detour of a trip is connected to fishing in the occupied area or just passing through the area. The model is generic and there are no limits as to how many areas to analyse or for what time period - all it needs is input data for the required area and time period. The efficiency of the model will increase if the proportions of vessels using position trackers increase.

As of method, we have used the results and distribution from data with coordinates as a sample to estimate the distribution of catch value without position data and what proportion of this value that belongs to specific locations. By doing so, we were able to estimate the total catch value caught in the wind farm areas, both with detailed data linked to coordinates and the estimate of values without position data. The key measures computed by our method is the total estimated value of fishing areas and the total detour caused by wind farms occupying spatial areas.

The model is based on three main outputs, all from code written in R:

1. An R script that retrieves a data frame where landing and closing notes are linked to the coordinates where the respective fishing vessel is believed to carry out the fishing activity and the value and weight of the catch is evenly distributed to these coordinates.

2. An R script that retrieves a data frame with the remaining landing notes that were unable to merge with coordinates.

3. An R script that retrieves a data frame with the calculated detour a fishing vessel must take in to account, given that one or several specific areas are occupied and the fishing vessels were to proceed driving as historical data dictates.

5.2 Prerequisites

We have made a few assumptions and prerequisites while developing the model that affects the results:

1. Fishing vessels cannot pass through the wind farms. They have to move around them.
2. When fishing vessels travel through areas planned for wind farms, between entry point and exit point, they travel the shortest possible way.
3. If a fishing area is occupied by a wind farm, the catch value inside is not lost. Fishing vessels can always find the same amount of catch value somewhere else.
4. When a fishing vessel travels to a similar fishing area, the increased competition in this area will not lead to a smaller amount of catch value per vessel or increasing the time it takes to land the catch.

5.3 Writing the R scripts

As described in the introduction to section 5.1, the model retrieves three main data frames that all are results of code written in R. When explaining how the model is programmed, we divide it in to those three outputs.

5.3.1 Output 1: Merging coordinates with landing and closing notes

The desired result of programming this script was to merge coordinates from the VMS and AIS data frames with the correct fishing activity that are filed in the landing notes. As VMS data points have an intermediary (the electronic logbook) before they are linked to the notes, the programming steps are a bit different than the ones who create a direct link between AIS and notes. We start by explaining the linking between VMS data and notes, thereafter, we supply what was done differently with the AIS data.

5.3.1.1 Merging VMS data to landing and closing notes

The necessary data to complete this output is electronic logbook data, VMS and landing notes. The data is loaded and we make sure there are no duplicates or errors.

Step 1: Identifying relationships between data frames and creating keys
In database theory, when trying to merge two data frames, a main concept is to detect relationships, or columns that contain identical values, which then can be used as connection keys to merge the data frames together (Date, 2013). In table 5.1, all relationships we identified between the three data frames are visualised.

Table 5.1: Relationships identified between the data frames

Data frame	Variables				
Electronic Logbook	*Call signal*	*Fishing gear*	*Fish species*	*Start time*	*Stop time*
VMS	*Call signal*	*NA*	*NA*	*Timestamp*	*Timestamp*
Landing notes	*Call signal*	*Fishing gear*	*Fish species*	*Timestamp*	*Timestamp*

Step 2: Addressing issues in electronic logbook data
From table 5.1, it might seem rather straight forward: Merge the data frames based on call signals, fishing gear, fish species and the timestamp that appears between the time of deploying and pulling up the fishing gear. However, there were some issues that arose, which had to be addressed first.

Issue 1: Logged duration in electronic logbook too short
Some logged lines in the electronic logbook have a duration that is either logged incorrectly short or that is shorter than the intervals VMS data is logged, so that it is not possible to merge VMS data to the line. This issue is solved by expedite the start time by one hour and extending the end time by two hours, to lines with a duration shorter than three hours.

Issue 2: Duration related to some types of fishing gear is misleading
There are lines in the electronic logbook that are logged with fishing gear that is immersed in the water, picked up several days/weeks afterwards, while the fishing vessel performs

other types of fishing activity in the meantime. Nets and pots are examples of such fishing gear. To avoid merging coordinates for the whole period between lowering and lifting the gear, we set the start time to four hours ahead of the end time on lines indicating the activity of such gear.

Step 3: Creating unique IDs for each catch

In order to implement the necessary measures in later steps, we assigned a unique ID to all lines that contained the same call sign, start and end time, fishing gear and fish species. This was simply done by adding a new column as a result of merging the five columns we just mentioned. The unique ID is further titled *UniqueERS*.

Step 4: Merging electronic logbook and VMS data frames

When the two issues regarding duration were addressed, we used the function sqldf (Section A0.1.1) to merge the electronic logbook data frame and the VMS data frame, by the conditions call signal equals call signal and Timestamp is between Start time and Stop time. Each line in the electronic logbook was merged with its respective coordinates, leaving no errors or loss of data due to merging. The merged data frame is from now of referred to as *ERS-merge*. The next steps were to add correct ID for main fishing areas to ERS-merge and then merge this data frame to the landing notes.

Step 5: Adding ID for main fishing area to ERS-merge

In the landing notes, there is a column, *Main area*, with values that indicates which main area the fish was caught in. In order to increase the merging accuracy, we decided to add this column as a condition. In order to add a merger condition, Main field equals Main field, both ERS-merge and the landing notes needed this column. By using the function points.in.polygon (Section A0.1.1), we looped through all the locations in MCAdf (Section 4.4) and returned the main fishing area ID to the respective ERS-merge coordinates. This resulted in adding Main field as a column to ERS-merge.

Step 6: Addressing issues in landing notes data

To merge ERS-merge with the landing notes, we were to use call signals, fish species, main area and time as merging conditions. The main issue when merging these data frames was the time condition.

Issue 1: Creating a time interval in landing notes

Electronic logbook data have a Start time and a Stop time, which enabled for merging the time of a VMS coordinate that were within this time interval. The landing notes only have one time dimension: The *landing time* of the catch. Thus, we needed to create a new variable, *previous landing time*, in the landing notes data. This was done by first assigning all the lines in the landing notes data frame that contained the same call sign, the same fish species and the same timestamp a unique ID in a new custom column *FishID1*, by merging the three columns together. Then, we created a new data frame called DistinctLanding, with distinct values of FishID1. Note that DistinctLanding data frame and the landing notes data frame have a unique relationship key, FishID1.

Further on in DistinctLanding, we were to arrange by time and group by call signal and fish species and use the lagged time values to find previous time of landing. However, in some cases, the same catch is posted at different times, which in this case would lead to a misleading value of the previous landing time.

To exemplify, Bob the fisherman has just returned from fishing. At 1p.m., he turns in half of his catch, then eats lunch. At 4p.m. he returns, and turns in the rest of his catch. So in the landing notes, it may look like he went out fishing 1p.m. and then returned with another catch at 4p.m. If not corrected for, the algorithm will try to find coordinates between 1p.m. and 4p.m. It will return no coordinates and the value from the 4p.m. notes will not be included.

To fix this issue, we grouped by call signal and fish species, arranged by time and calculated the time difference between the lines. A new ID column, *FishID2* was made, that assigned a new unique ID if the time difference was less than 24 hours, and kept the same ID from FishID1 if the time difference was larger than 24 hours. Thus, Bob's fishing notes from 1p.m. and 4p.m. now have the same FishID2, even though the FishID1 is different. Further on, we transferred FishID2 to the respective lines in the landing notes data frame by merging DistinctLanding and landing notes by their unique column FishID1. Then we made a new data frame, *DistinctLanding1*, by filtering distinct values of FishID2 in DistinctLanding. Note that DistinctLanding1 data frame and the landing notes data frame have a unique relationship key, FishID2.

After correcting for issue 1 in step 6, we were left with three data frames of importance: DistinctLanding1, ERS-merge and the landing notes. ERS-merge and DistinctLanding1 were to be merged, and then FishID2 could link this new merged data frame to the landing notes.

Step 7: Merging ERS-merge and DistinctLanding1

As in step 4, we used the function sqldf (Section A0.1.1) to merge the ERS-merge and DistinctLanding1 data frames by the conditions call signal equals call signal, Fish species equals Fish species and Timestamp is between landing time and previous landing time. This new data frame is referred to as *LandingVMS*.

Further on, the last steps involve linking the catch value and weight from landing notes to LandingVMS and distributing the respective values equally across the coordinates, and then define which catch is within offshore wind farms.

Step 8: Distributing weight and value across the coordinates

As an example of what LandingVMS contain and what needed to be done to distribute correct value and weight, we will again use the fictive fisherman Bob. During his fishing trip, he fished the same species at three different locations, leaving three lines in the electronic logbook. At each location, he logged the estimated gross weight of the catch under the column Round weight. After merging ERS-merge and DistinctLanding1 to LandingVMS, the three lines from the electronic logbook now had the same FishID2, though each line also has its own unique ID, UniqueERS, as mentioned in step 4, and they have x number of coordinates distributed over x lines with the same UniqueERS.

In order to distribute the correct value to the different locations, we created another unique ID by merging the FishID1 and UniqueERS columns. This new ID is referred to as FinalID. The ID represents each location in each fishing trip, and was created to be able to make a data frame with distinct values of each location without coordinates. This new distinct data frame is referred to as *DistinctERS*. The three locations Bob was fishing at, is now represented by three lines, and they can all be linked to their coordinates through the ID UniqueERS.

Bob reported different round weight at each location, thus each location should be given a fraction of the total value , given its reported weight. To obtain this, we grouped by FishID2 and - in Bob's case - summed the total value of the three reported round weights and divided its reported round weight on this total sum. Then each line was left with a percentage that represented its fraction of the catch value and weight. This percentage was stored in a column named *FractionOfValue*.

Over to the landing notes. All the landing notes were given a FishID2, that matched with the same FishID2 in the data frame DistinctERS. In the landing notes, we grouped by FishID2, summed value, gross weight and product weight, and created a new distinct data frame with the total weights and values for each FishID2. This new data frame is referred to as *DistinctNotes*. We then merged DistinctNotes and DistinctERS by FishID2 and then had a data frame, referred to as *ERSNotes*, with both correct value and weight and the lines reported in the electric logbook. To obtain the correct fraction of weight and value for each line, we multiplied the value and weight obtained from DistinctNotes and multiplied it by the column FractionOfValue. Then, each line was given the correct fraction of the total value reported in the landing notes. To add coordinates to each line, we merged ERSNotes with LandingVMS by FishID2 and obtained the final data frame *ERSVMSFinal*.

Final work in this step is to distribute the value equally across the coordinates in ERSVMSFinal. If Bob was fishing for six hours on his first location, then there were probably about six coordinates linked to this fishing trip's location and the same FishID2. To distribute the value and weight across the six coordinates, we grouped by FishID2, counted the number of lines (How many coordinates), divided one by that count, and multiplied the value and weight by the quotient. Thus each coordinate is assigned the same value and weight.

Step 9: Adding variable that indicates if inside offshore wind area or not
In the final step, we were to create a variable that indicated if the coordinates in ERSVMSFinal were inside a offshore wind area or not. By using the function points.in.polygon (Section A0.1.1), we looped through all the locations in OWAdf (Section 4.4) and returned 1 if inside offshore wind area, 0 if not.

5.3.1.2 Merging AIS data to landing and closing notes

As previously mentioned, the way we merged AIS to landing notes was rather similar to how we merged VMS and landing notes. However, there where a few differences, and we will present them in this section.

Step 1: Adding a measure for speed to AIS data

VMS data is linked to electronic logbook and through the information from the logbook, we were able to identify the periods during which fishing activity was carried out. With the AIS data, on the other hand, we had to manually create a method to identify fishing activity. The method we chose to filter out AIS data that probably was not linked to fishing activity was by applying a speed filter. According to Souza et al. (2016), most large fishing vessels conduct fishing at a speed slower than or equal to five knots. In order to filter based on speed, we had to create a speed variable in the AIS data frame.

The AIS data has a variable called Speed Over Ground (SOG). This is the speed on the exact moment the data was logged. However, the data is logged on an hourly interval, and we wish to know the average speed during the hour, to obtain a more accurate understanding of the fishing vessels' movement. To create the new speed-variable, we group by the vessels identification tags, their Call signals, and arrange given ascending time. Then we compute the time in hours between a given point and its previous point and use the function distCosine (Section A0.1.1) to compute the distance in kilometres between a given point and its previous point. We find kilometres per hour and then knots by using respectively equation 5.1 and 5.2 (MetricConversions, 2018).

$$Kilometres\ per\ Hour = \frac{Distance\ in\ Kilometres}{Time\ in\ Hours} \tag{5.1}$$

$$Knots = Distance\ in\ Kilometres \times 0.5399568 \tag{5.2}$$

Further steps: Similar to VMS

Further on, the process of merging AIS to the notes were similar to the VMS. We added main fishing area and considered using this as a condition for merging. However, this led to about 1 billion in value disappearing, which indicated that fishermen probably log the main area incorrectly in some cases. Thus, we chose not to use main area as a merging condition. After fixing time intervals like we did in step 6, we merged AIS with the remaining landing notes, ergo the notes not merged with VMS.

Detecting fishing activity

Before distributing value and weight we took measures in order to source out activity that was most likely not fishing activity. The first measure was implementing a speed filter, assuming vessels conducting fishing activity on average do not exceed a speed of five knots (Souza et al., 2016). To avoid losing trips that did not contain speed below five knots, we made a condition for the speed filter: Only apply filter if the trip contains two or more data points with five knots or slower. Otherwise, we could end up deleting a trip that in reality were linked to value, but outside our assumed filter.

Further on, we removed coordinates close to docks where fishing vessels land their catch. This was done by implementing the Docksdf, that contains coordinates of all docks and mark a radius of 100 metres from the centre coordinate of the dock. We removed all coordinates within this radius. As with the speed filter, we also conditioned that the trip had two or more data points outside the radius of a dock, because the vessel could be fishing close the dock in some cases.

The third measure was making sure that the vessels were not anchored and inactive. If, the vessels usual anchoring location is outside of the dock location taken to account in the second measure, we had to make sure that these anchoring/inactive coordinates were removed. To do so, we filtered out all coordinates that had a change in distance from previous coordinate smaller than 30 metres. As with the two previous measures, we conditioned that the trip had two or more data points outside not included in the filter, because the vessel could either be fishing very static or just randomly drift right at the same location of where the previous coordinates were logged.

After removing data points that were most likely not related to fishing activity, we distributed value and indicted offshore wind areas as in step 8 and 9, respectively.

5.3.2 Output 2: Landing notes without coordinates

About 80 percent of the value from the landing notes were successfully merged to coordinates from VMS or AIS. The remaining 20 percent, were filtered out in a separate data frame. Even though one can not tell the exact location of where this value belongs, the landing notes do provide information such as catchment areas, and the location of where the fish was handed in.

5.3.3 Output 3: Detour calculator

The desired output from this script was a data frame with the calculated detour fishing vessels were forced to take if the planned offshore wind areas around Trana were declared no go zones between 2016 and 2019. We used the AIS and VMS data to simulate the routes the fishing vessels completed during the time period and then inserted and calculated the fastest detour around, if the route went through an offshore wind area.

We used point.in.polygon (section A0.1.1) with AIS, VMS and OWAdf as input variables and used the result to indicate when a vessel entered and exited an offshore wind area. Then we computed the fastest possible route from the entrance point to the exit point by using distCosine (section A0.1.1) and the fastest possible detour around the offshore wind area. If the detour was larger than the original tour, then we extracted the original tour distance from the detour distance and found the detour in kilometres.

5.4 Valuating the fishing areas

In this section, we will describe how we chose to evaluate each fishing area where the three offshore wind farms are planned to be in the Træna area.

The data frame from output 1 provides detailed information of the location to where fish have been caught between 2016 and 2019. Output 2 also contains information regarding fishing activity, but the granularity is more coarse than output 1. In table 5.2, a full assessment of each tracking type is visualised. Based on this assessment, when estimating the value of each area, we have chosen to first evaluate the fishing areas based on AIS/VMS data, and then use the distribution of this data frame to estimate where the values are located in the data frame without coordinates. Further on is the procedure we used to accomplish this.

Table 5.2: Assessment of data sources

Measures/ Tracking type	VMS	AIS	No Tracking
Granularity	*Medium*	*Medium*	*Low*
Accuracy	*High*	*Medium*	*Low*
Credibility	*High*	*Medium*	*Medium*

5.4.1 AIS/VMS-data

All data from output 1 contains a value that indicates whether a coordinate is inside an offshore wind farm or not and the name of the wind farm. When measuring the estimated value inside a wind farm based on AIS/VMS data, we sum and filter based on these variables.

5.4.2 Data without tracking

The data from output two does not have fine-grained position data in the form of coordinates. However, they are marked with a specific catch area that covers a large area. This is illustrated in figure 5.1. From this figure, we can see that most of Træna Vest is located in catch area 06-26 and 06-27, Trænafjorden Sør in 06-31 06-33 and Trænafjorden Nord in 06-31.

Figure 5.1: Catch areas around Træna (Source: DoF map services)

The way we have chosen to estimate the value inside a wind farm that does not have tracking information is by finding the total value inside each catch area based on the data frame from output 2. Then, we use the catch values from output 1 and calculate the percentage of the value using value inside a wind farm area as nominator and value inside catch area as denominator. These percentages are also filtered by year, fish species and length group, to increase the accuracy of the algorithm. The output of this algorithm (equation 5.3) is the expected percentage of catch value inside a catch area that also is inside a wind farm, based on the sample of values that is linked to position data. To find the total value of a wind farm area, we summarise the output from equation 5.4 with the value inside wind farm with position data. The calculation for each wind farm is visualised in table A0.5, A0.7 and A0.6.

$$Percentage\ of\ value\ inside\ wind\ farm = \frac{Value\ inside\ wind\ farm\ with\ position\ data}{Total\ value\ with\ position\ data\ in\ catch\ area} \tag{5.3}$$

$$Estimated\ value\ inside\ wind\ farm\ without\ position\ data = Percentage\ of\ value\ inside\ wind\ farm \times Total\ value\ without\ position\ data\ in\ catch\ area \tag{5.4}$$

5.5 Measuring the externalities

This thesis is limited to calculating externalities only in the form of increased labour hours and fuel costs as a result of increased travelling distance caused by detours. We have categorised detours in two main groups, approach 1 and approach 2:

1. Detour that must be taken when travelling to a fishing ground outside the wind farm area, but travelling through the wind farm area to reach the fishing ground.
2. Detour as a result of fishing in a wind farm and now having to find a similar fishing ground elsewhere.

Further on, we will explain our method of measuring the detours in each approach, thereafter we will explain the input variables used to compute additional labour hours and fuel cost.

5.5.1 Approach 1: Detour when moving around a wind farm to reach designated fishing area

In this approach, we only use data from actual events measured through output 3, the detour calculator. This output is the detour each vessel must complete to go from point A to point B and a wind farm now is located in their normal carriageway. However, this output measures a detour also if the vessel is fishing inside the wind farm on its way. Detours regarding fishing inside the wind farm is taken to account in approach 2 and in order not to calculate a detour for a specific trip by two approaches, and by that overestimate the detour distance, we filtered out all detours in output 3 that was linked to a trip where 50% or more of the catch value was caught inside a wind farm. This was done by creating a unique key in output 3 that was a joint between call sign date/time and latitude/longitude. In output 1 we did the same, thus we had a unique key in each data frame that could transfer information regarding catch value by each trip in output 1 over to the respective rows in output 3. A binary value of TRUE/FALSE could then filter out detours in output 3 where more than 50% of the value in the value pr trip was caught in a wind farm.

5.5.2 Approach 2: Detour as a result of fishing in a wind farm and now having to find a similar fishing ground elsewhere

As in the way we valuated the fishing areas, this approach is done by first measuring AIS/VMS data and then use this distribution as a sample on the data without coordinates. However the procedure is a bit different, and is described in the following.

5.5.2.1 AIS/VMS data

To measure detours caused by being forced to fish somewhere else, because the catch value of the trip is inside the wind farm, we decided to first define a fishing trip by a vessel and then define if this trip was in fact inside of a wind farm or not. The first part was ok, each row in output 1 has a column that states the trip ID, ergo one unique ID for each trip by a vessel. Further on, as we touched in to in Approach 1 (section 5.5.1), we decided to define a trip as "Inside wind farm" if the ratio *wind farm value pr trip vs total value pr trip* was larger than or equal to 50% (equation 5.5).

$$\textit{wind farm value pr trip vs total value pr trip} = \frac{\textit{Value inside wind farm pr trip}}{\textit{Total value of trip}} \qquad (5.5)$$

After defining the trips where the vessel would be forced to fish elsewhere, we also had to estimate the actual distance of the specific detour. To do so, we analysed the fishing activity characteristics by each catch area (figure A0.9, A0.9, A0.11, A0.13, A0.15, and A0.16). This analysis lead to the categorisation of trips as shown in table 5.3.

Table 5.3: Categorisation of trips within wind farms

Category	Wind farm	Gear	Catch area
1	*Træna Vest*	*All*	*06-26 and 06-27*
2	*Trænafjorden Nord*	*Yarns and pots*	*06-31*
3	*Trænafjorden Nord*	*All but Yarns and pots*	*6-31*
4	*Trænafjorden Sør*	*Yarns and pots*	*06-31 and 06-33*
5	*Trænafjorden Sør*	*All but Yarns and pots*	*06-31 and 06-33*

After categorising the trips, we created heat maps based on the level of concentration of catch value filtered by the category variables. We added a circle from the centre of each wind farm and adjusted the radius in nautical miles until we had somewhat equal proportion of value within the circle as within the wind farm and defined this radius as the distance necessary to travel in order to reach a similar fishing area. The outcome from this procedure lead to the detours in nautical miles as shown in table 5.4. Finally, we multiplied the estimated detour for each category with the count of trips within each category and received the total estimated detour in nautical miles.

Table 5.4: Detours in nautical miles estimated for each category of trips within offshore wind farm

Category	Wind park	Gear	Catch area	Detour in NM
1	*Træna Vest*	*All*	*06-26 and 06-27*	*70.2*
2	*Trænafjorden Nord*	*Yarns and pots*	*06-31*	*7.1*
3	*Trænafjorden Nord*	*All but Yarns and pots*	*6-31*	*9.72*
4	*Trænafjorden Sør*	*Yarns and pots*	*06-31 and 06-33*	*10.8*
5	*Trænafjorden Sør*	*All but Yarns and pots*	*06-31 and 06-33*	*12.96*

5.5.2.2 Data without tracking

The way we have chosen to estimate the count of trips inside a wind farm that does not have tracking information is by finding the total count of trips in each area based on the data frame from output 2. Then, we use the count of trips from output 1 and calculate the percentage of the trips using the count of trips inside a wind farm area as nominator and total count of trips inside catch area as denominator. These percentages are also filtered by length group, year and the gear-categories as shown in table 5.3, to increase the accuracy of the algorithm. The output of this algorithm (equation 5.6) is the expected percentage of counted trips inside a catch area that also is inside a wind farm, based on the sample of counted trips that is linked to position data. To find the total detour caused by a wind farm area, we summarise the output from equation 5.7 with the value inside wind farm with position data. The calculation for each wind farm is visualised in table A0.9 and the total estimated detours distributed by length groups is in table A0.10.

$$\textit{Percentage of count of trips inside wind farm} = \frac{\textit{Count of trips inside wind farm with position data}}{\textit{Total count of trips with position data in catch area}} \tag{5.6}$$

$$\textit{Estimated count of trips inside wind farm without position data} =$$

$$\textit{Percentage of count of trips inside wind farm} \times \textit{Total count of trips without position data in catch area} \tag{5.7}$$

5.5.3 Input variables to compute labour hours and fuel costs

The externalities in the scope of this thesis, additional hours of labour and increased fuel costs, all caused by the detours fishing vessels must take to account if wind farms are implemented in Træna. We will now briefly explain the variables we use to calculate these measures.

5.5.3.1 Additional labour hours

Additional labour hours is a measure of how many hours in total, the detours will entail. It is a measure that can be interpreted as a socio-economic loss in the form of lost labour hours. To compute this measure, we convert the detours, which are presented in nautical miles, to time format, assuming the speed of a vessel conducting non-fishing activity is on average ten knots (equation 5.8). Then we use the variable *Average crew* from the profitability analysis

$$\textit{Hours pr nautical mile} = \frac{\textit{distance in nautical miles}}{\textit{10 (knots)}} \tag{5.8}$$

This measure, hours pr nautical mile is multiplied by the average number of crew pr vessel, based on the numbers from the profitability analysis prepared by DoF.

5.5.3.2 Additional fuel costs

An algorithm from The Food and Agriculture Organization (FAO) is applied to compute the hourly consumption of fuel. It is based on a vessels maximum motor capacity in horse powers (HP), the density of the fuel (D), specific consumption of due in grams/HP/hour (S), time in hours (H), The percentage of max capacity of HP used (C), and the formula is shown in equation 5.9 (The Food and Agriculture Organization, 2020). The full algorithm is visualised in appendix in figure A0.18.

$$\textit{Consumption of fuel} = C \times HP \times \frac{S}{D} \times H \times 0.001 \tag{5.9}$$

5.6 Resume of methodology

We have developed a model based on coding in R, where we successfully have linked vessel position data to landing notes and consequently managed to distribute catch value towards coordinates that mark the positions where each respective fishing activity was carried out, making us able to estimate the value of specific areas with a high degree of resolution. The model is generic and there are no limits as to how many areas to analyse or for what time period - all it needs is input data for the required area or time period. The model has many applications, including value assessment and analysis of patterns related to fishing activity and traffic at sea.

We have also developed a method based on the model, to estimate the distribution of catch value without position data and what proportion of this value that belongs to specific locations. To do so, we use values with position data and filter them based on the highest resolution of location obtainable through values without coordinates, which in this case are so-called catch areas. Then, we locate the catch areas surrounding the detailed location we want to evaluate, in this case wind farm areas in Træna. For each total value within a respective catch area, we find the proportion of this value that is inside of the target location, based on values with coordinates. This proportion is further on multiplied by the values without position data, registered within the same catch area, thus we achieve the estimated value within this catch area, that is caught within the wind farm areas.

6 Results

We estimate that within Træna Vest, Trænafjorden Nord and Trænafjorden Sør, the catch value in the time period from 2016 to 2019 was NOK 22M, NOK 5.2M and NOK 6.2M, respectively (table 6.1). The total detour in nautical miles is estimated to 1449, 3357 and 5061 respectively, and the total additional labour hours is estimated to 2135, 784 and 1927 (table 6.2). The total additional fuel costs due to the detour are estimated for each respective wind farm to NOK 12.6M, NOK 0.2M and NOK 1.16M (figure 6.1 and 6.2).

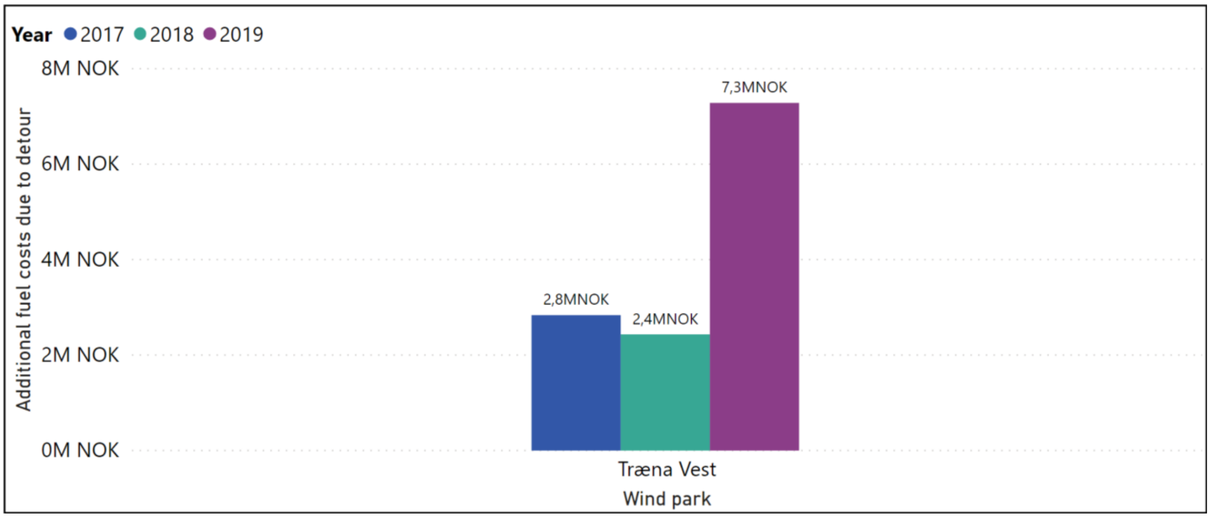


Figure 6.1: Estimated additional fuel costs in Træna Vest

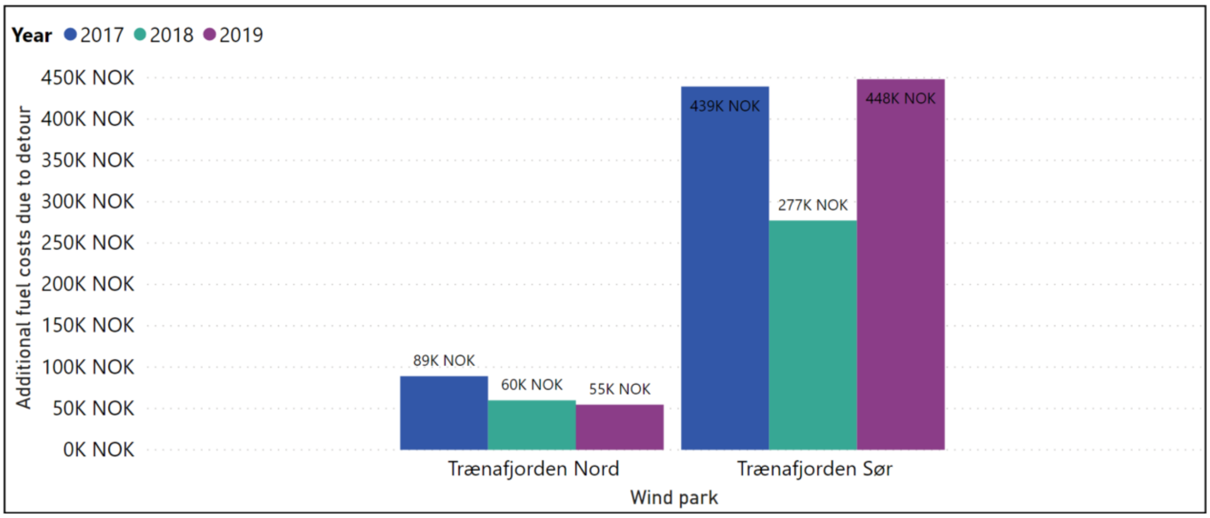


Figure 6.2: Estimated additional fuel costs in Trænafjorden Nord and Sør

Table 6.1: Estimated total value from fishing activity in planned wind park areas around Træna

Wind park	Estimated value wind park no tracing	Value of wind park tracing only	Total value of wind park	Total value of wind park average per Year
Trana Vest	677 100 NOK	21 359 974 NOK	22 037 074 NOK	7 345 691 NOK
Tranafjorden Nord	2 037 673 NOK	3 176 774 NOK	5 214 447 NOK	1 738 149 NOK
Tranafjorden Sør	646 809 NOK	5 552 183 NOK	6 198 991 NOK	2 066 330 NOK
Total	**3 361 581 NOK**	**30 088 931 NOK**	**33 450 512 NOK**	**11 150 171 NOK**

Table 6.2: Estimated total detour from either moving to other fishing grounds due to wind park (approach 2) or moving around wind park to reach designated fishing ground (approach 1).

Reason for detour	Detour approach 1			Detour approach 2: With coordinates			Detour approach 2: Without coordinates			**Total**		
Wind park	Detour NM	Detour in hours	Fuel cost	Detour NM	Detour in hours	Fuel cost	Detour NM	Detour in hours	Fuel cost	**Detour NM**	**Detour in hours**	**Fuel cost**
Træna Vest	1449	2135	12,56MNOK				0	0	0,00MNOK	**1449**	**2135**	**12,56MNOK**
Trænafjorden Nord	432	139	0,11MNOK	1581	407	0,01MNOK	1524	237	0,08MNOK	**3537**	**784**	**0,20MNOK**
Trænafjorden Sør	1787	694	1,01MNOK	2624	1070	0,06MNOK	636	163	0,09MNOK	**5048**	**1927**	**1,16MNOK**
Total	**3668**	**2968**	**13,67MNOK**	**4205**	**1476**	**0,08MNOK**	**2161**	**400**	**0,17MNOK**	**10034**	**4845**	**13,92MNOK**

The total catch value landed in Træna municipality between 2016 and 2019 was NOK 450M, where 83% of this value was caught by large pelagic trawlers fishing in the green area marked in figure 4.4, approximately 85 nautical miles North West of Træna. However, as we soon will elaborate, some of the wind farm areas are of importance, in particular for smaller vessels. The catch value inside the wind farms Nord and Sør accounted for 11.2% of the total value landed in Træna municipality by vessels smaller than 15 metres. This is visualised in figure 6.4. Further on in the results, we analyse each wind farm area to provide a more detailed presentation of the main results.

Figure 6.3: This is a heatmap of where the catch value landed in Træna municipality is mainly caught. 88% of the total catch value NOK 450M is caught within the green area.

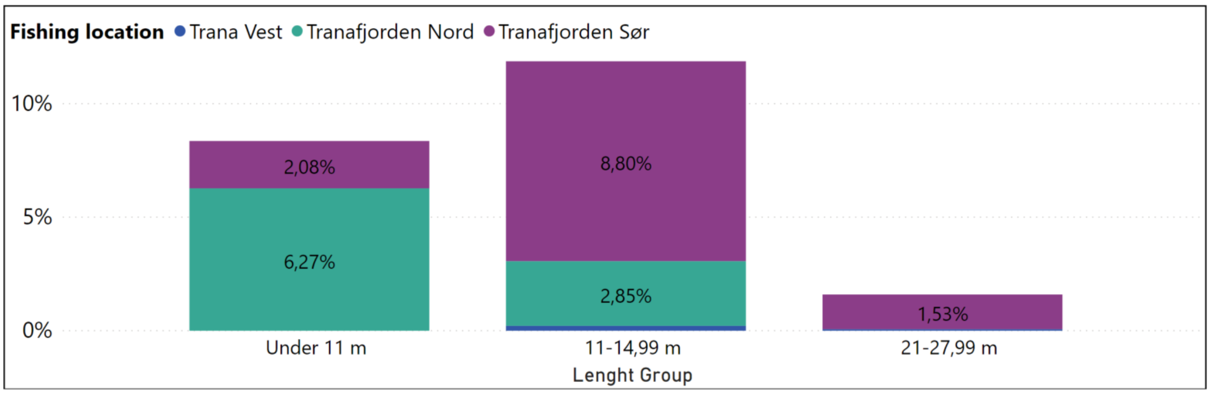


Figure 6.4: Y-axis: Share of value landed in Træna caught within respective wind farm areas.

6.1 Træna Vest

Valuation of area and significance for individual vessels

Overall, we estimated a total catch value of NOK 22M in Træna Vest between 2016 and 2019, and about 12,5% of the total value caught in the respective catch areas 06-26 and 06-27 at the same time interval (table A0.5). However, close to 100% of the value in Træna Vest is caught by vessels larger than or equal to 28 metres. If we look at the proportion caught in Træna Vest compared to the total value in catch area 06-26/27, filtered by vessels larger than or equal to 28 metres, the value inside Træna Vest accounts for 22% of the total value (table 5.4). Further on, we can keep in mind that the analysis of Træna Vest mainly contains vessels larger than or equal to 28 metres, meaning 100% of this fleet is using position tracking, so the analysis is purely based on data with coordinates.

Most vessels fishing inside Træna Vest have a ratio between the catch value caught inside Træna Vest and the value caught overall in total, lower than 1% (this measure is further referred to as *wind park vs total value ratio*). This is visualised in figure 6.5 where the total value caught within Træna Vest is on the X axis and the wind park vs total catch value ratio is on the Y axis. The vessels are clustered in three categories, depending on the values in the X and Y axis. From this figure, we can see that the catch value of Træna Vest for each vessel is relatively low, compared to their total catch value and that only five vessels have a ratio larger than two.

If we look at total value caught, then filter this value to catch area 06-26/27, five vessels depended almost 100% on the value caught inside Træna Vest, accounting for an overall value of about NOK 7M. This is visualised in figure 6.6, where the X- and Y axis and the vessel cluster are the same as in 6.5, however the figure is filtered to only account for values from catch area 06-26/27. This plot tells us how important the value in Træna Vest is compared to what is caught in the mentioned catch areas. We can see that several vessels gain a moderate to high share of their catch value within Træna Vest when fishing in catch area 06-26/27.

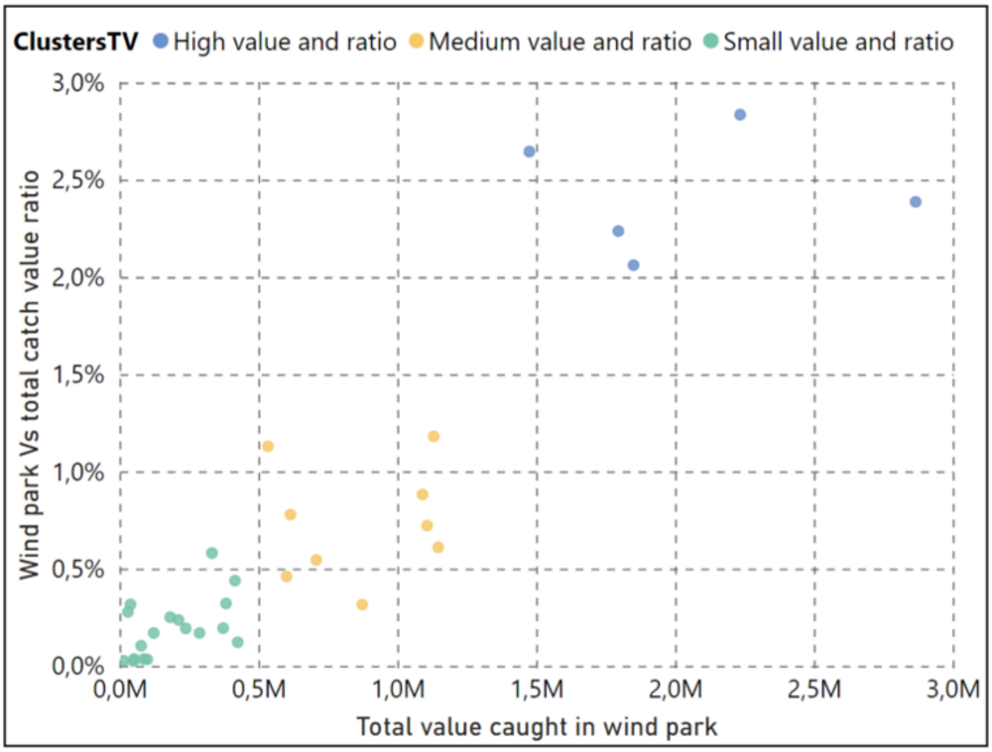


Figure 6.5: Wind park vs total value ratio equals the proportion between the value a vessel gain inside the wind park, compared to the total value gained thorough the time period. The legend "ClusterTV" equals Cluster Træna Vest, and is an automatically cluster function distributing vessels by their values.

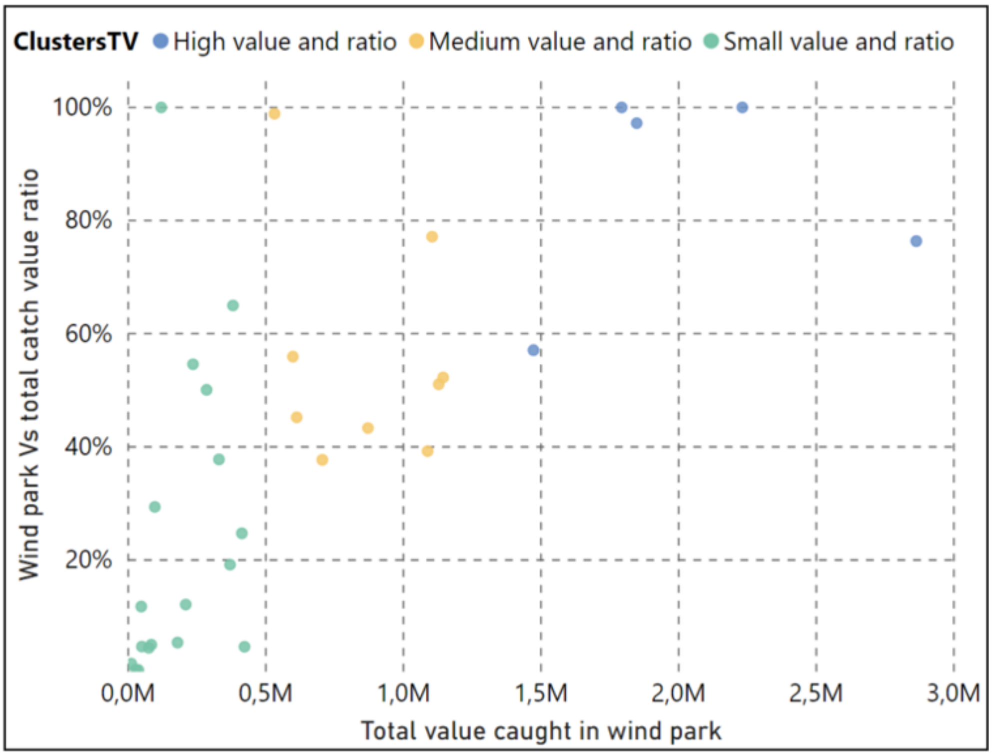
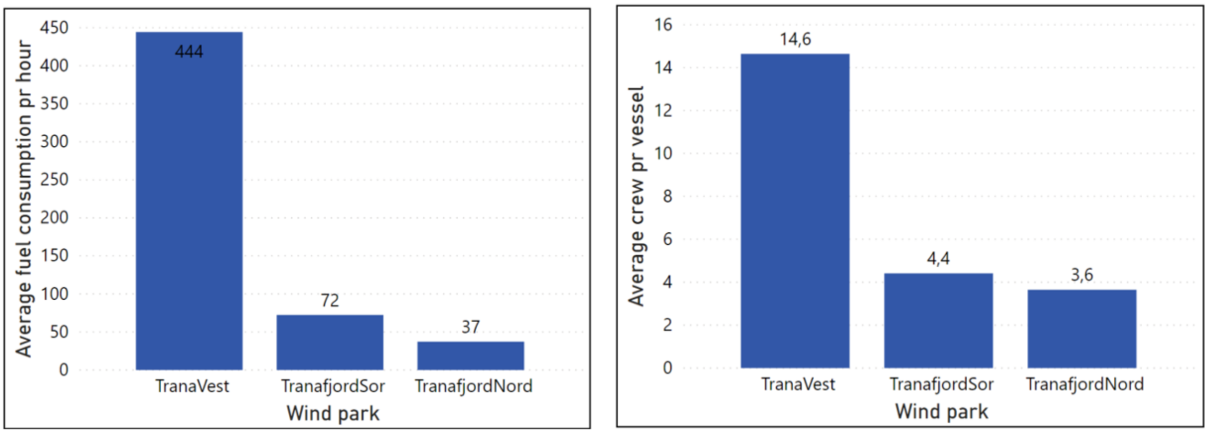


Figure 6.6: Wind park vs total value ratio equals the proportion between the value a vessel gain inside the wind park, compared to the total value gained thorough the time period. The values in this figure is filtered to account for values inside catch area 06-26/27. The legend "ClusterTV" equals Cluster Træna Vest, and is an automatically cluster function distributing vessels by their values.

Detours and additional fuel costs and labour hours in Træna Vest

Our model computes Træna Vest to be the area which causes the lowest total distance in detours measured in nautical miles compared to the other wind parks. However, the total amount of additional labour hours due to detours is higher than the other wind parks and the total amount of fuel costs accounts for as much as 90% of the total costs of all the wind parks. The reason behind this contradiction is visualised in figure 6.10. In this figure we can see the average fuel consumption and crew per hour based on the vessels driving through each wind park. The fleet driving through Træna Vest is mainly based on vessels larger than 28 meters (figure 6.2) and this entails a much larger crew and fuel consumption, making this fleet more vulnerable to the effects of detours.



(a) Average fuel consumption pr hour based on vessels driving through wind park

(b) Average crew pr hour based on vessels driving through wind park

Figure 6.7: Average fuel consumption and crew members pr hour based on vessels driving through each wind park

Reason behind detours in Træna Vest

Another important finding related to Træna Vest, is the reason behind the detours. As shown in table 6.2, 100% of the detours are categorised as detours caused by driving around wind park to reach other fishing grounds (approach 1). This indicates that there were no trips between 2016 and 2019 where 50% of the catch value or more was linked to Træna Vest, thus no calculated detours to find similar fishing areas. It also indicates that Træna Vest is a a popular passage for large vessels which are on the way to fish somewhere else.

By linking the detour coordinates with the fishing coordinates, we discovered that 88% of the NOK 12.6M fuel costs were related to detours where the vessel is fishing far away from catch area 06-26/06-27. This signals that the detours linked to fishing close to Træna Vest are less significant and that the main costs driver is trips through Træna Vest to fish further out in the sea. This is visualised in figure 6.8 where the overall legend categories in green and blue indicates if the detour is related to fishing within catch area 06-26/27 or not. From the left we see the percentage of total fuel costs distributed in the categories, in the middle the number of trips for each category, and to the right the count of distinct vessels operating in each category.

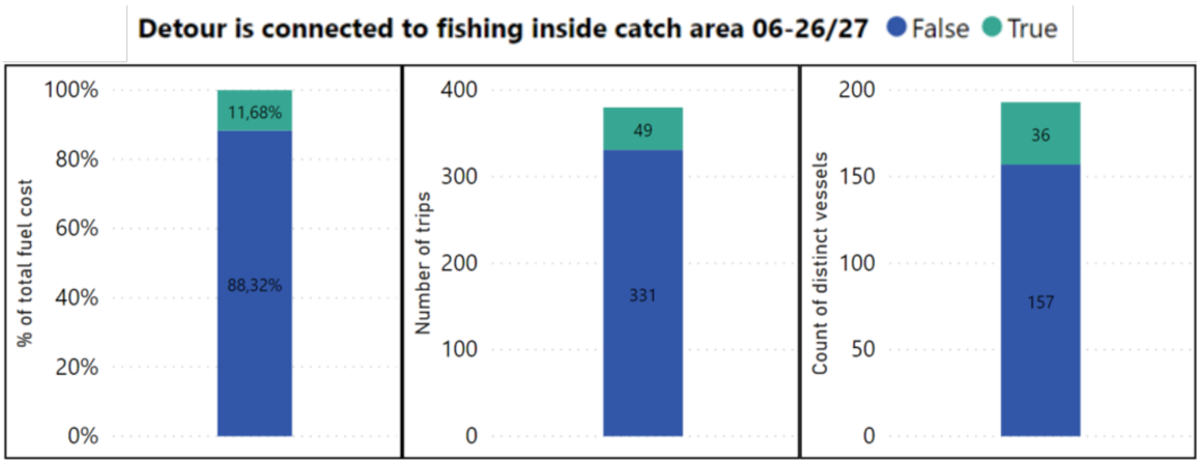


Figure 6.8: Left: % of fuel cost by T/F | Middle: Count of detours | Right: Count of distinct vessels | Legend: Binary of true and false, where true indicates that the detour is connected to fishing inside catch area 06-26/27. false indicates that the detour is connected to fishing far away from Træna Vest.

Detours and significance for individual vessels

The summarised fuel costs among the top ten vessels with the highest additional fuel costs, accounts for 42% of the fuel cost caused by detours to fishing areas far away from Træna Vest. The ratio between additional fuel costs and total catch income for these vessels are between 0.2 and 0.5%. This is visualised in figure 6.9, where the total additional fuel costs per vessel is on the X axis and the ratio between additional fuel costs and total catch income is on the Y axis. These vessels are clustered to *Cluster 1*, to show their total additional fuel costs towards the rest of the fleet, *(Blank)*. These results implies that the additional fuel costs impact is rather centred towards certain vessels and that the operating margin for these vessels will be reduced by a small but not insignificant share.

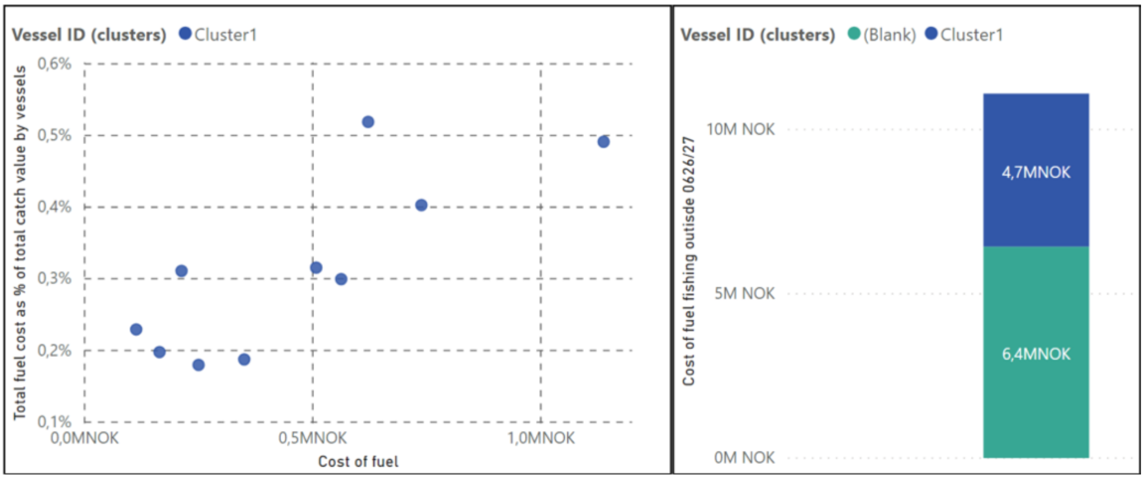


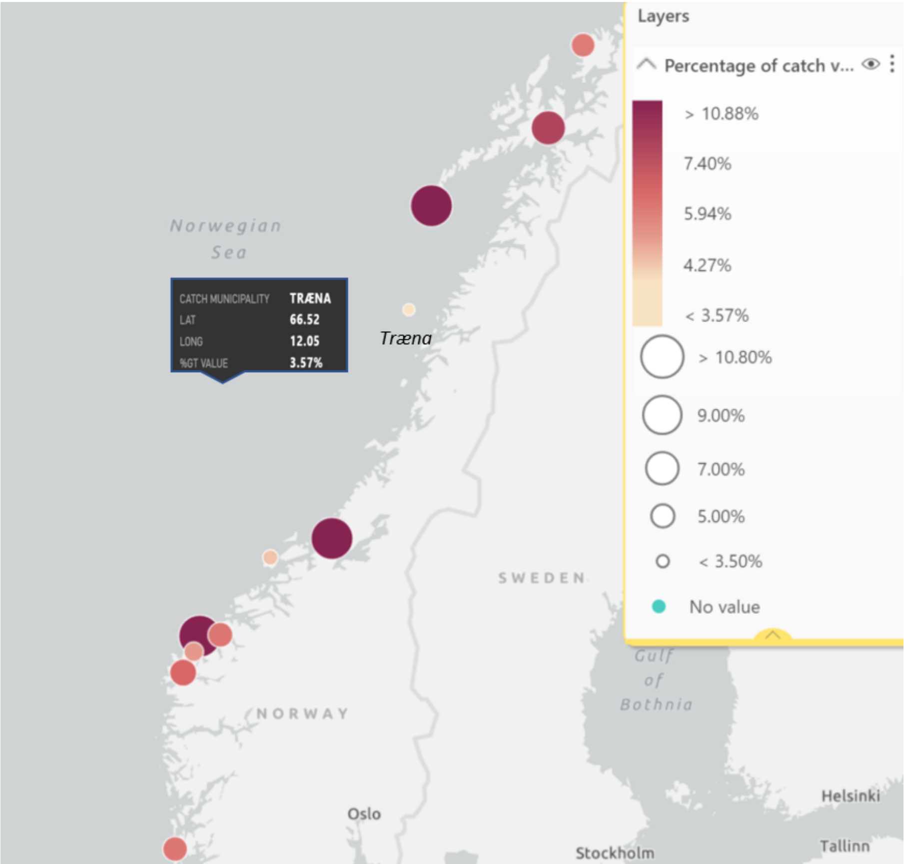
Figure 6.9: Left: Cluster of top ten vessels based on the measure Fuel cost/Total catch value | Right: Fuel cost divided in vessels included in cluster and not in cluster | Filter: Fishing outside Træna Vest | Legend: Cluster 1 is vessels with highest additional fuel costs compared to income in fish value. Blank includes the rest of the feet.

Economic consequences for the local commercial fishing industry in Træna

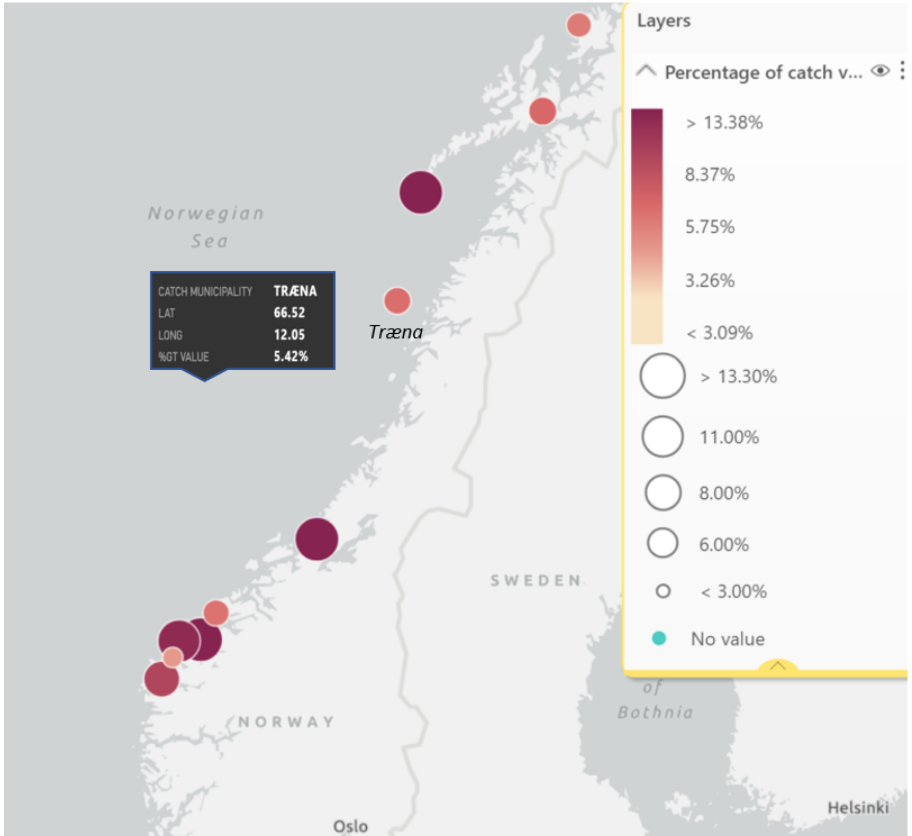
Of the NOK 22M caught inside Træna Vest between 2016 and 2019, only 3.57% was landed and sold in Træna municipality. These 3.57%, or NOK 0.7M were caught by five vessels, whereas only one of those vessels was registered in Træna. This vessel accounted for 4% of the NOK 0.7M that was caught in Træna Vest and sold in Træna. The distribution to where the catch value was landed and sold is visualised in figure 6.10a. Here we can see that most of the value caught in Træna Vest, is landed in Møre and some in Lofoten.

Worst case scenario Træna Vest

As a worst case scenario given that the development of the wind farm is carried out, we have mapped an area around Træna Vest, calculated its value and the distance to the closest similar fishing ground (figure 6.11). The total catch value of the area in this scenario is estimated to NOK 127M, distributed on 192 trips, leading to additional 235 269 litres of fuel, additional fuel costs of NOK 3.06M and 9140 additional labour hours (table 6.4). As the catch values are concentrated close to Træna Vest, and this is seemingly a rather seldom steam of pelagic fish so close to land, the scenario seem to some some extent relatively likely. As for individual vessels, most vessels the ratio between catch value inside scenario compared to total catch value is on average 2% while 10 vessels have a ratio between 4% and 9%, making them rather exposed to this scenario. Figure 6.10b maps the distribution to the different locations where the catch value inside the worst case scenario was landed and sold. 5.42% of the NOK 127M was landed in Træna, making the municipality relatively unexposed to this scenario.



(a) A map of where the catch value caught inside Træna Vest is landed and sold. The values are shown in percentage of the total value in Træna Vest. The colour and size codes are explained in the top right corner. The value is mainly sold either in the Lofoten area or in Møre.



(b) A map of where the catch value caught inside the worst case scenario of Træna Vest. The values are shown in percentage of the total value inside the scenario area. The colour and size codes are explained in the top right corner. As we can see, the value is mainly sold either in the Lofoten area North of Træna or in Møre, south of Træna

Figure 6.10: Maps of catch value caught within Træna Vest (6.10a) and within worst case scenario boundaries (6.10b) and landed in Trana municipality

Column ID	Column name
1	Count of trips
2	Value of catch area
3	Additional fuel in litres
4	Additional fuel costs
5	Additional labour hours

Table 6.3: Column names to table 6.4

	1	2	3	4	5
1	192.00	NOK126 994 294	235269.00	NOK3 058 502	9140

Table 6.4: Worst case scenario Træna output of calculation from model

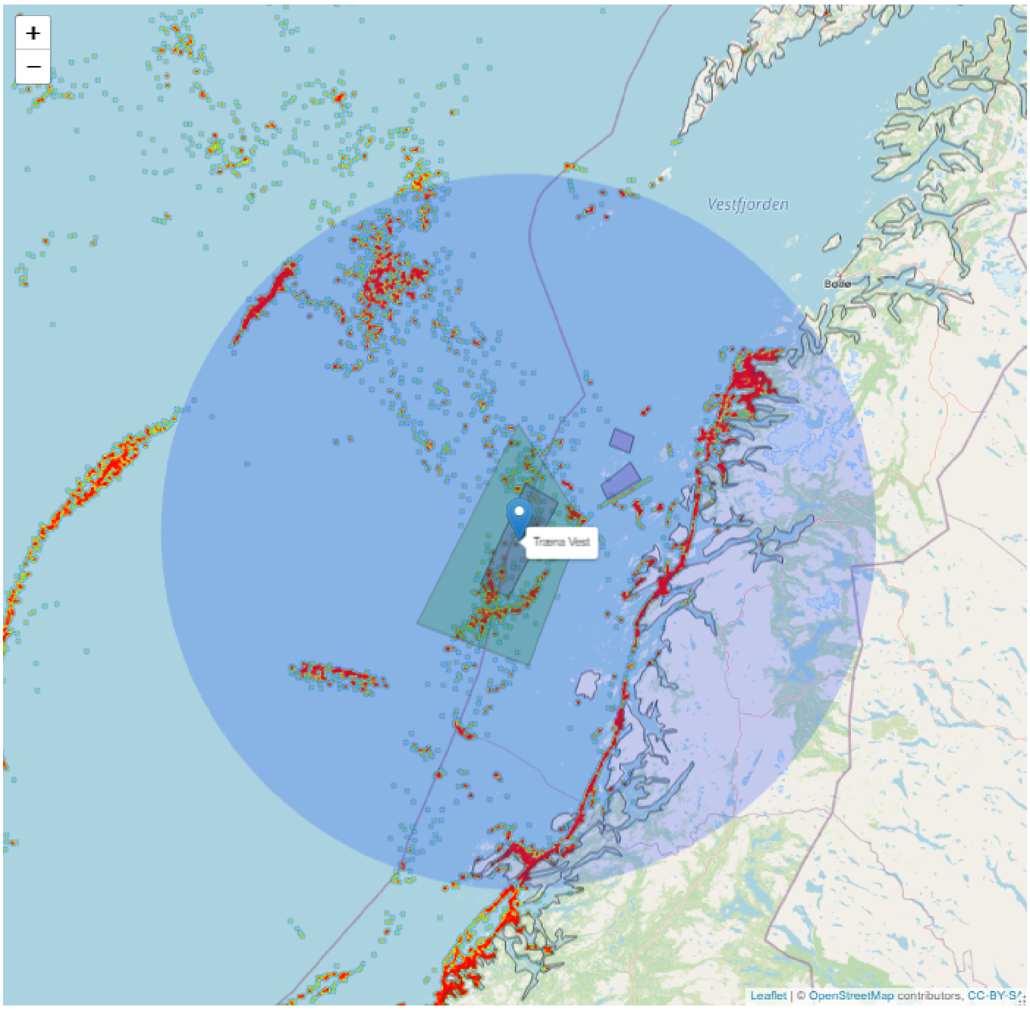


Figure 6.11: A map of worst case scenario Træna Vest, where the green polygon indicates the extent of the scenario where Træna Vest causes the fishing ground in catch area 0626- / 27 to dissolve. This area is one of few areas where pelagic fish linger relatively close to land and the blue radius of 84 nautical miles indicates the distance to a similar fising ground.

6.2 Trænafjorden Sør

Valuation of area and significance for individual vessels

Overall, we estimated a total catch value of NOK 6.2M in Trænafjorden Sør between 2016 and 2019. Within the catch area that covers Trænafjorden Sør the most, 06-33, we have estimated that about 9.11% of the total value caught in the catch area 06-33 is within Trænafjorden Sør (table A0.7 and A0.2). The total distinct count of vessels operating in the respective areas is 722, while the distinct count of vessels with coordinates within Trænafjorden Sør is 57. The main value inside Trænafjorden Sør is caught by vessels below 15 metres and the main species caught is cod by 76% (figure A0.12, A0.13 and table A0.7). Further on, when analysing the effects on individual vessels operating in Trænafjorden Sør, we must keep in mind that these analysis are based on data with coordinates only, which entails that about 50% of the vessels under 11 metres are not taken into account. Thus, the specific count of vessels mentioned is an underestimation.

Most vessels fishing in Trænafjorden Sør have a wind park vs total catch value ratio above six percent. This is visualised in figure 6.12 the total value caught within Trænafjorden Sør is on the X axis and the wind park vs total catch value on the Y axis. The result signals that the area is of some importance to the vessels fishing there, but still the main portion of catch value is caught elsewhere.

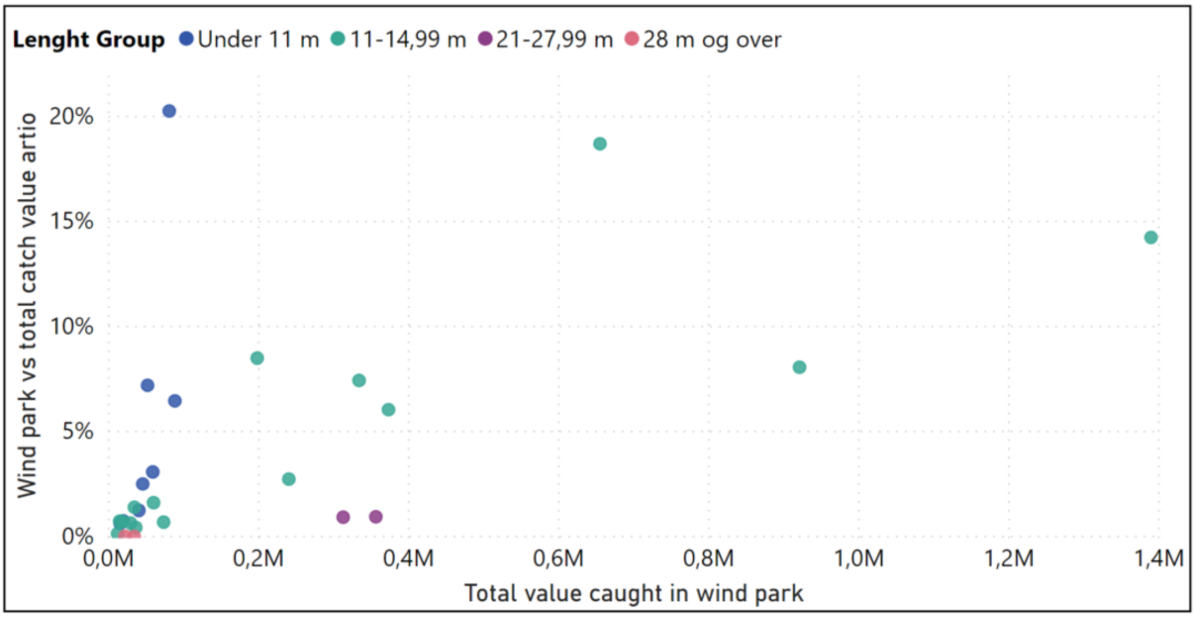


Figure 6.12: Wind park vs total value ratio equals the proportion between the value a vessel gains inside the wind park, compared to the total value gained. The legend categorise vessels in length groups

Detours and additional fuel costs and labour hours in Trænafjorden Sør

Trænafjorden Sør is both a busy area larger vessels tend to travel through, as well as a popular fishing area for smaller vessels. The main driver of additional fuel costs is caused by vessels often travelling through the area, accounting for about 87% of the total estimated fuel costs of NOK 1.16M. The detours caused by finding a replacement fishing area (approach 2) is the leading cause of additional labour hours, accounting for 64% of the 1927 (table A0.10).

Detours and significance for individual vessels

There are 10 vessels with a ratio between additional fuel costs and total catch income larger than 0.3 percent. These vessels account for about 45% of the total additional fuel costs due to detour in Trænafjorden Sør. This is visualised in figure 6.13 where the total additional fuel costs pr vessel is on the X axis and the ratio between additional fuel costs and total catch income is on the Y axis. These results implies that the additional fuel costs is to some degree centred and that the operating margin for some vessels will be reduced by a small but not insignificant share.

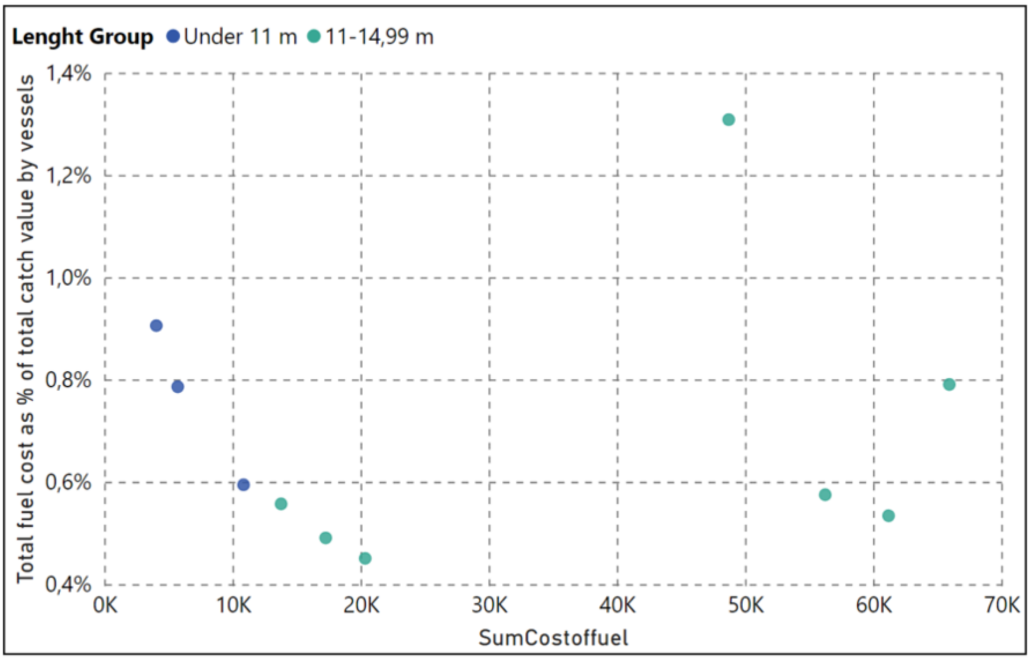


Figure 6.13: Visualisation of the sum of additional fuel cost on the X axis and the ratio between fuel cost pr vessel and income in catch value pr vessel. Legend categorise vessels in length group

Economic consequences for the local commercial fishing industry in Træna

Of the NOK 6.2M caught within Trænafjorden Sør between 2016 and 2019, 84.9% was landed and sold in Træna municipality. For vessels in length group under 11 metres and 11-14.99 metres, the percentage caught in Trænafjorden Sør and landed in Træna municipality is 89% and 91.3%, respectively. This is visualised in figure 6.14, where the X axis is length group and the Y axis the percentage of value from Trænafjorden Sør, landed in Træna municipality.

About 40% of the catch value in Trænafjorden Sør was caught by 18 vessels registered in Træna, and this catch value accounts for 5% of the total value caught by these vessels. The results are visualised in figure 6.15 where the count of distinct vessels categorised in municipalities on the X axis and the value caught within Trænafjorden Sør on the Y xis.

The results implies that the fishing area within Trænafjorden Sør is relatively important to the local fishermen and the community. However, the value caught inside Trænafjorden Sør and landed in Træna municipality is only a percentage of the total value landed in Træna municipality. On the other hand, value caught in Trænafjorden Sør and landed in Træna municipality filtered on vessel length under 15 metres, accounts for about 6% of the total value landed.

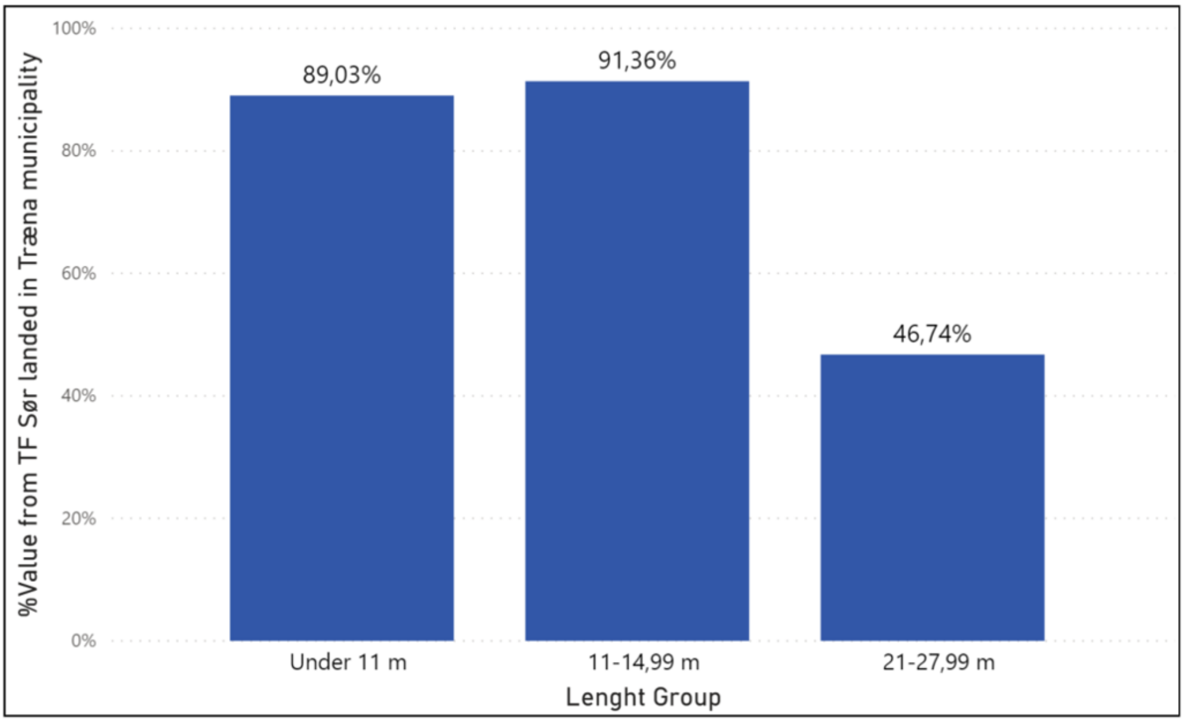


Figure 6.14: Percentage of value caught within Trænafjorden Sør that was landed and sold in Træna municipality.

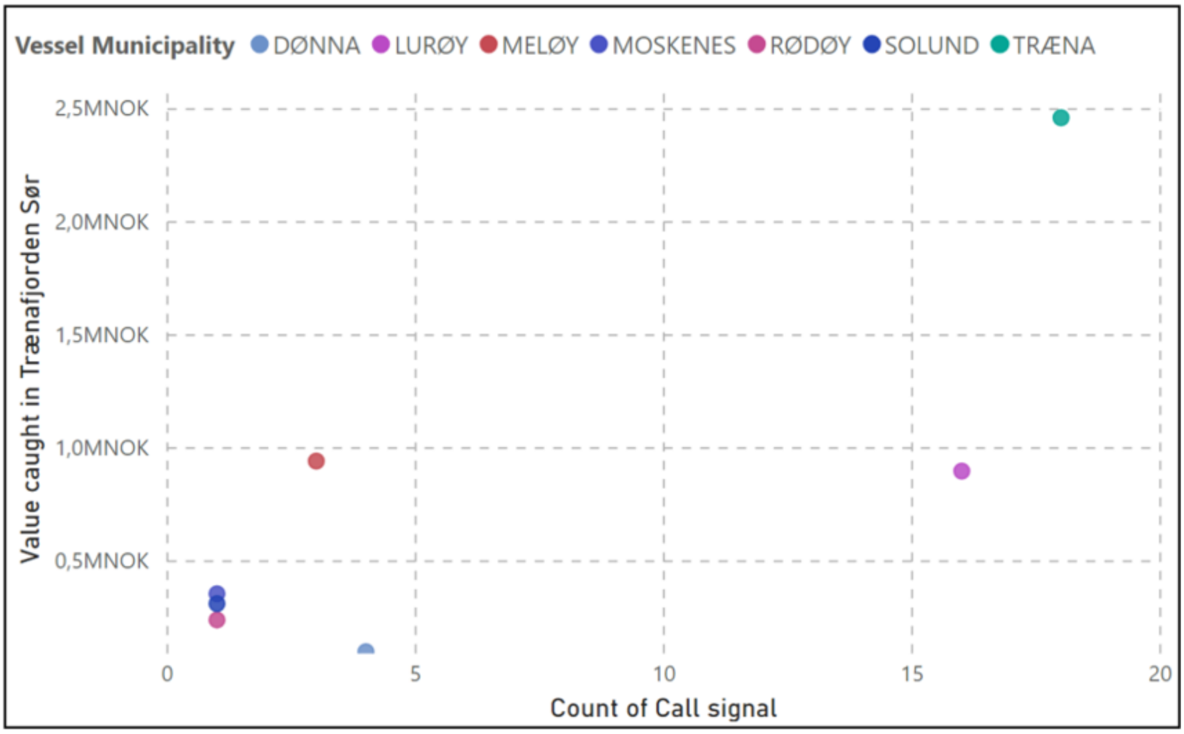


Figure 6.15: Plot with the distinct count of vessels fishing in Trænafjorden Sør, the total value caught in Trænafjorden Sør on the Y axis, categorised by what municipality the vessel is registered in.

Worst case scenario Trænafjorden Sør

We have generated a worst case scenario for Trænafjorden Sør. This is given its location being very close to and also surrounding spawning grounds and a rearing field, which are highly important areas both for future fish growth and current fishing. The spawning grounds and rearing field are visualised in figure 6.16. In the worst case scenario, the area where the spawning grounds and rearing field gets destroyed by raising Trænafjorden Nord and there will no longer be possible to fish there anymore. The area we marked as destroyed is visualised within the green polygon in figure 6.17, where we also created a heatmap of catch value within the area.

The consequences of this scenario would be fatal for the local community at Træna. Based on the data with coordinates, NOK 49M were caught and landed in Træna municipality within the boundaries if the scenario. If the sample distribution of this data is applicable to the data without coordinates, another NOK 18M is caught in this area by vessels without tracking gear and landed in Træna municipality. This is a total of NOK 67M and accounts for 78% of the total value caught and landed in Træna municipality by vessels under 15 metres.

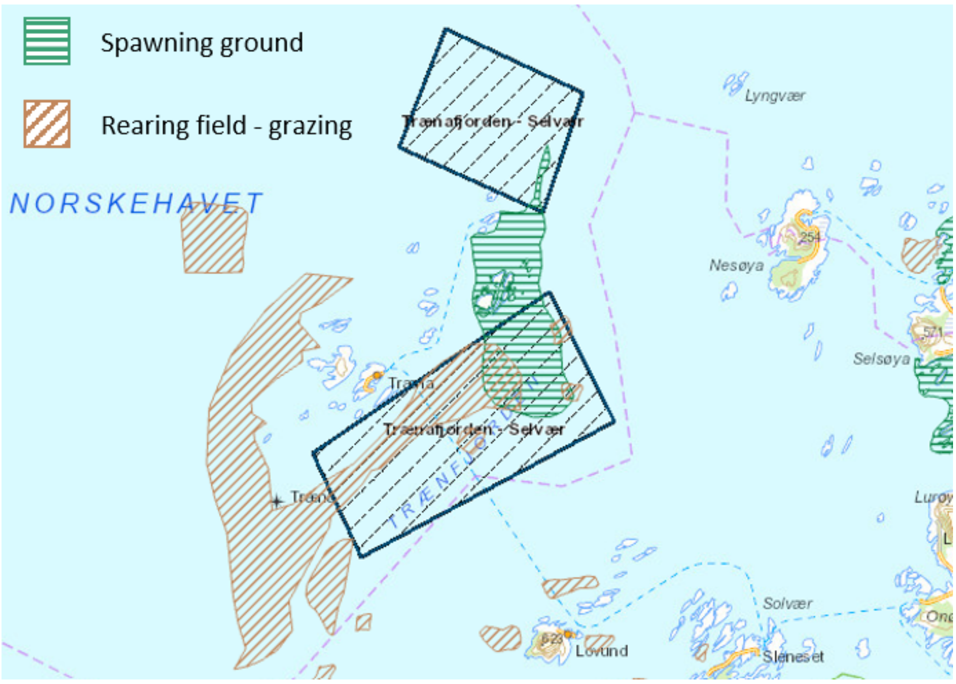


Figure 6.16: Map of spawning grounds and rearing field close to Trænafjorden Sør. The data is generated from the map services to DoF and is based on the data collection *Coastal data*.

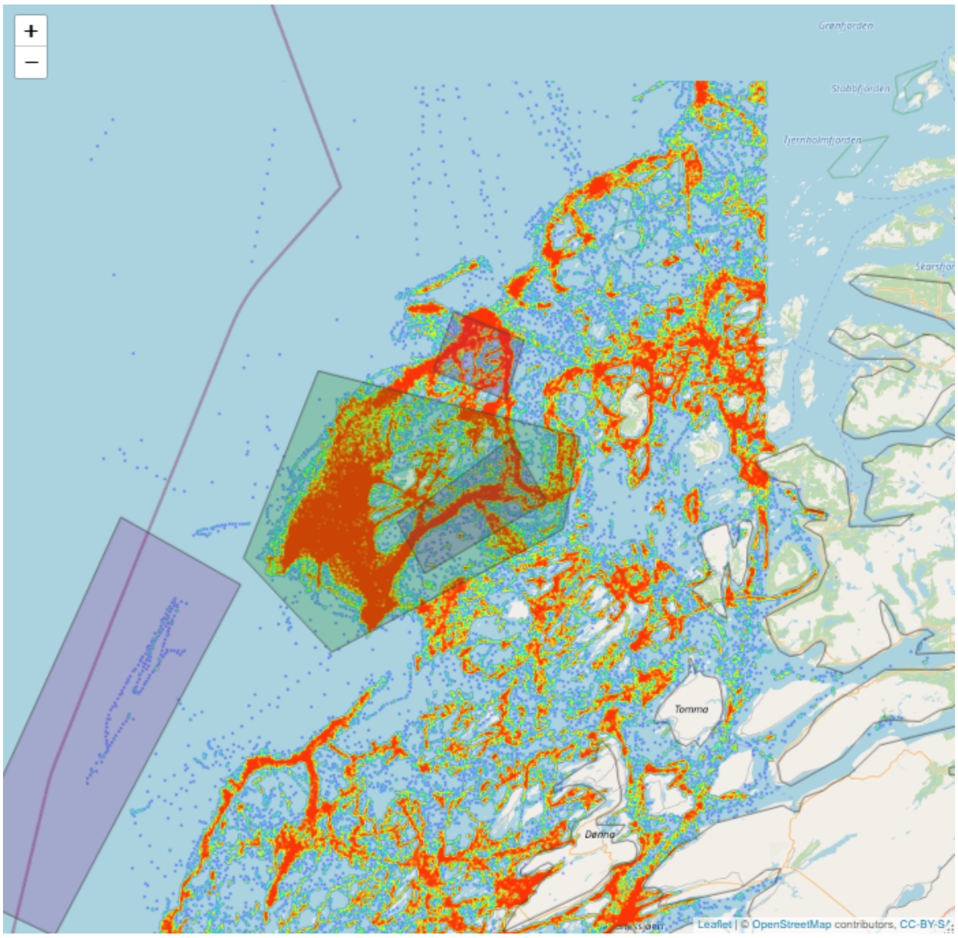


Figure 6.17: Map of worst case scenario Trænafjorden Sør. It is a heatmap based on catch value in the area. The purple polygons are the wind farms, the one in the middle is Trænafjorden Sør. The area we marked as destroyed is visualised within the green polygon.

6.3 Trænafjorden Nord

Valuation of area and significance for individual vessels

Overall, we estimated a total catch value of NOK 5.2M in Trænafjorden Sør between 2016 and 2019. This accounts for 8.9% of the total value caught in the respective catch area 06-31 (table A0.6 and A0.2). Within Trænafjorden Nord, we registered fishing activity from fishing vessels under 15 metres only and taking into account that larger vessels are obliged to use tracking monitors, we can assume that there were no vessels 15 metres or larger fishing within the wind park between 2016 and 2019. The total distinct vessels observed fishing in Trænafjorden Nord was 20. Of the four catch areas, 06-31 is the one with the lowest concentration of vessels being tracked, especially those under 11 metres. The percentage of vessels being tracked in this length group is about 40%, which is important to bear in mind when reading the analysis regarding individual vessels, which is only based on data with coordinates. Thus, the count of vessels under 11 metres in these estimates will be an underestimation.

There were five vessels fishing within Trænafjorden Nord that accounted for 78.14% of the total value caught inside the wind farm area. These five vessels were all registered in Træna municipality and had a wind park vs total catch value ratio between 8% and 25%. This is visualised in figure 6.18. The total value caught within Trænafjorden Sør is on the X axis and the wind park vs total catch value on the Y axis. The result signals that the catch value caught is rather centred towards a small group of vessels, and for these vessels, the fishing area inside the Trænafjorden Nord is of medium to high importance.

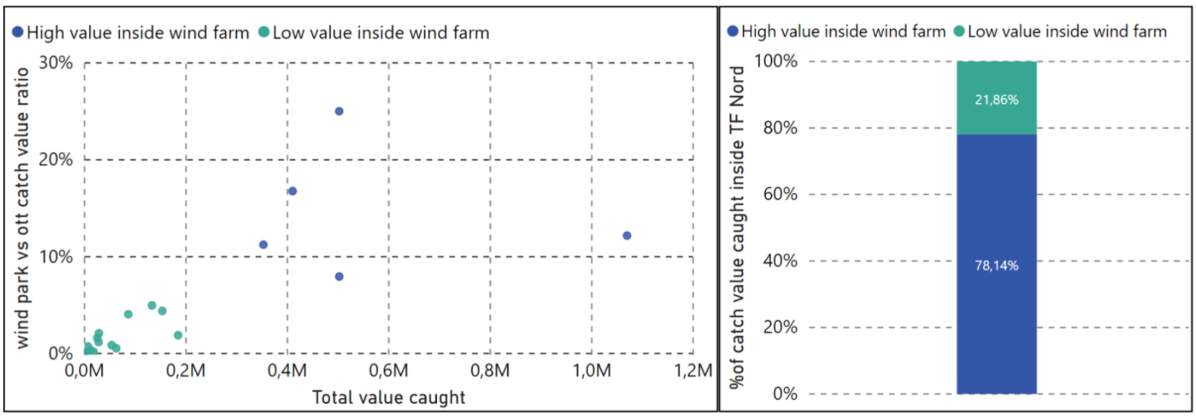


Figure 6.18: Wind park vs total value ratio equals the proportion between the value a vessel gain inside the wind park, compared to the total value gained. The legend categorise vessels in length groups

Detours and additional fuel costs and labour hours in Trænafjorden Nord

Trænafjorden Nord is a popular ground to fish using yarns and pots for vessels under 11 metres, and this is the main driver for the detours in this area. About 72% of the additional detours in nautical miles is within this category, whereas 60% of this is an estimate from data without coordinates. The additional fuel costs per vessel due to detours are all insignificant and there are no ratios compared to total catch value, larger than 0.2%.

Economic consequences for the local commercial fishing industry in Træna

Of the NOK 5.2M caught within Trænafjorden Sør between 2016 and 2019, 60% or NOK 3.2M was landed and sold in Træna municipality. Of the NOK 3.6M delivered, about 80% was caught by vessels from Træna municipality. These results are visualised in figure 6.19 where we see the total value caught in Trænafjorden Nord and landed in Træna municipality, divided in vessels registered in Træna municipality and vessels from other municipalities and 6.15. The results implies that Trænafjorden Nord is a popular fishing ground for both vessels landing in Træna municipality and other municipalities.

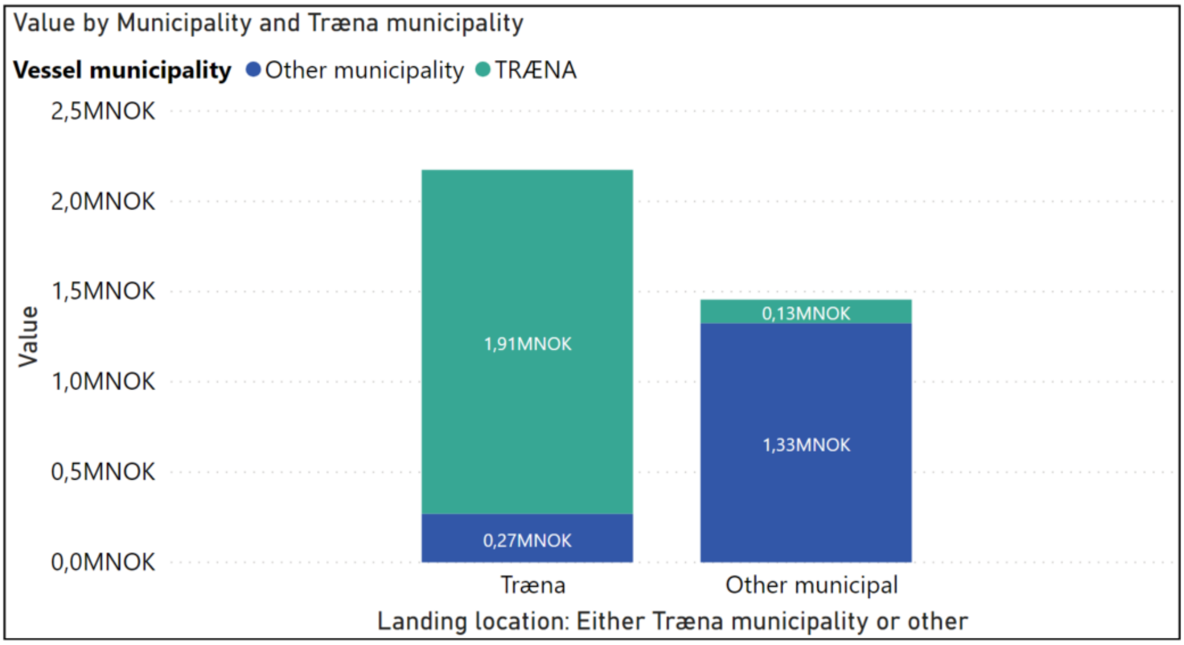


Figure 6.19: Percentage of value caught within Trænafjorden Sør that was landed and sold in Træna municipality.

6.4 Resume of key results

The catch value caught in Træna Vest is of little importance to the local community surrounding Træna, the local fishermen in Træna and to the large trawlers fishing in the area. However, Træna Vest is a trafficked area for vessels fishing further out in the sea, and additional fuel costs caused by detours moving around Træna Vest is estimated to NOK 12.6M between 2016 and 2019 with additional consumption of fuel of about 1M litres diesel. Additionally, there is a worst case scenario linked to opening the wind farm Træna Vest, destroying a fishing ground valued to NOK 127M over three years.

Trænafjorden Sør is is a relatively important fishing ground for local fishermen in Træna, accounting for 9.11% of the total value caught in its respective catch area. Almost half of the value in Trænafjorden Sør is caught by locals from Træna municipality, and about 90% of the total value caught in Trænafjorden Sør is landed in Træna municipality. However, this is only a fraction of the total value landed in Træna municipality, which makes the landing value relatively insignificant for the municipality in terms of work related to handle landings, and not in terms of local fishermen. Additionally, there is a worst case scenario in which opening the wind farm Trænafjorden Sør leads to destroying the spawning grounds and rearing fields in Træna. This scenario would be rather fatal to the local fishermen as the catch value within this outlined scenario accounts for 78% of the total value caught and landed in Træna municipality by vessels under 15 metres.

Trænafjorden Nord is is a relatively important fishing ground for local fishermen in Træna, accounting for 8.9% of the total value caught in its respective catch area. This area is not very trafficked and the main cause of detours in this area is due to finding similar fishing grounds that must replace the one inside Trænafjorden Nord. Between 2016 ad 2019 there were five vessels registered in Træna that were quite dependent on catch within Trænafjorden Nord, whereas one vessel caught 25% of its total catch value within the wind farm area.

7 Discussion

7.1 Discussion of the results

In this section, we will discuss the results in light of our thesis research question:

What are the economic consequences of establishing offshore wind farms in Træna for the local community and the fleet operating in the respective areas?

As we described in the results, the different wind farms all have distinct specifications and effects on fishermen and the community of Træna. The externalities caused by the wind farms are measured in additional fuel costs and additional labour hours. The additional fuel costs were not significantly decisive in either of the wind farm area cases, but they did account for a couple of percents of total catch value for some vessels. Those vessels will experience a reduced profit, which will involve financial losses not only for the vessel owners, but also the fishermen belonging to the vessel. This is due to the *Share-based remuneration schemes* (Lottfiske), which is a compensation scheme often used by Norwegian fisheries, where a share of the catch value profit is shared amongst the fishermen (Fiskarlaget, 2020). Increased fuel costs, lead to decreased profits and by this also decreased wages per fisherman.

The additional labour hours entail a lower hourly wage for each fisherman on the current vessel, and a socio-economic loss in the sense that these hours could have been used to gain the society in some way. This is also refereed to by economists as an opportunity cost. For the fisherman himself, it will be a productivity loss and a lower wage per hour. However, since most fishermen are rewarded through share-based remuneration schemes, a fixed monthly amount or both, it is difficult to measure additional costs for the vessel holder as a result of increased labour hours on board. Arguably, if all the labour costs are monthly fixed or fixed due to the net catch value, the only additional costs for the vessel holder due to detours might be the increased fuel costs, while the additional labour hours only affect the fishermen. However, this is given that the catch value is maintained at normal level. As we discuss in the model limitations, there is also a probability of reduced catch value due to decreased spatial areas and increased competition within the remaining fishing grounds. Our model assumes this is not going to happen, but if it does, both fishermen and vessel holders in Træna will suffer a further financial loss.

Overall, Trænafjorden Sør seems to be the area that will induce the greatest economic consequences for the local community in Træna. A large concentration of the local fleet depends on the fishing grounds within the area and most of the catch value inside is landed in Træna. As of catch value distributed through the landing port of Træna and by this creating labour, non of the wind farm areas bring even a fraction of the total value, which is mainly caught by large trawlers far out West. However, the fleet of Træna consists of 25 vessels under 15 metres, and they will all in individual ways be affected by the implementation of both Trænafjorden Sør and Nord. The worst case scenarios also deem a rather great threat both for vessels within the fleet of Træna, but also the larger trawlers fishing in catch area 06-26/27. Such risks, including destruction of spawning grounds and NOK 100M worth of fishing grounds, advocate that the arguments for developing offshore wind farms in the three areas must be convincing and and as a minimum expectation benefit the Norwegian people, more than the potential losses they will entail.

The current Norwegian commercial fishery industry is a sustainable industry providing a substantial surplus each year. Having this in mind, in addition to the risks involved developing wind farms in popular fishing grounds, there should be signals at hand, clearly indicating that offshore wind will benefit the Norwegian people. The only offshore wind project carried out under the auspices of the Norwegian government is Equinor's project, Hywind Tampen. This project had initial investment costs close to NOK 5Bn. Due to rules in the tax regime, they may end up being able to depreciate NOK 4.5Bn over a six-year period. In other words, Equinor only needs to pay NOK 500 million, and any interest costs additionally, so at the end of the day, this project is heavily subsidised with help from the Norwegian tax payers (Martiniussen, 2019).

As of future profitability and funding of Norwegian offshore wind, the prime minister of Norway, Erna Solberg, recently stated that the Norwegian Government do not plan to subsidise future offshore wind projects (Mollestad, 2020). However, this statement may not be wind proof, considering the relatively high costs involved in developing offshore wind on Norwegian continental shelf, as documented by Hirth (2020). Taking this uncertainty to account in addition to the risk of effecting then commercial fishing industry, we argue that when deciding whether to develop offshore wind farm in Træna or not, a solution based on coexistence and a solution the fishermen accept should be emphasised heavily.

7.2 Limitations in the estimation model

When developing the model, we created an algorithm linking position data to landing notes. We also made four prerequisites that have shaped the outcome of the results. We will now discuss the limitations regarding the algorithm and then discussing the prerequisites, their validity and whether they correspond to reality or not.

7.2.1 Limitations regarding algorithm that links position data to landings notes

The valuation of fishing grounds, relies to a relatively large extent on correctly distributing value from landing notes to coordinates that were logged when the fishing vessel performed fishing activity. When developing generic models, it is difficult and to some extent probably impossible to take in to account every individual variable that defines how a vessel conduct fishing activity. However, we have studied fishing patterns to the different fishing gears and length groups and striven to detect and take to account for the most common signals that characterise fishing activity and non-fishing activity.

As of VMS data, we are rather confident that the landing notes have found the correct coordinates, because the electronic logbooks provided a specific time interval to link when fishing activity was conducted. As of AIS data, the risk of misplacement of values is greater, as the time period for fishing activity is based on our own parameters and delimitations. However, specific to our study of Træna, all coordinates seem to fit the description of locations for fishing grounds, according to the coastal data developed by DoF, which indicates that the model is working as it is meant to (figure 7.3).

Another more advanced approach of detecting fishing activity, is developed by Syver Storm-Furu (2019), as he in his master's thesis investigates the possibility of detecting fishing activity by using machine learning on AIS and VMS data. An interesting approach, that could be a way to strengthen our model in terms of accuracy of fishing activity detection. Further on, we will discuss the prerequisites.

7.2.2 Prerequisite 1: Vessels are not allowed to drive through a wind farm area

According to DoF, fishing vessels are facing many possible hazards when driving through offshore wind farms. Examples of these hazards are interference in communication and navigation instruments due to the motion of turbine blades, and risk of collision with the windmills (Directorate of Fisheries, 2012). In Belgium, all non-maintenance vessels have to remain at least 500 meters away from wind parks, and in England and Denmark fishermen are allowed to fish inside wind farms, but doing so at their own risk (Bolongaro, 2017). Based on this, we find it reasonable to assume that vessels are not allowed passage within wind farms developed in Norway.

7.2.3 Prerequisite 2: When fishing vessels travel through areas planned for wind farms, between entry point and exit point, they travel the shortest possible way

The resolution to each vessels position data is usually on an hourly basis, making it difficult to compute the exact steps the vessels make inside the wind farm area. That is the reason for prerequisite 2. It is unlikely that each vessel travels the shortest possible distance from entrance point to exit point, leading to a possible overestimation of the computed detour distances. However it is also unlikely that the vessel is able to make the shortest possible detour, as our model also computes. This setting is a factor that might lead to an underestimation of the computed detour distances.

7.2.4 Prerequisite 3: If a fishing area is occupied by a wind farm, the catch value inside is not lost - Fishing vessels can always find the same amount of catch value somewhere else

For large vessels, this assumption may be true, because they have a large operating radius, which enables them to reach more distant fishing grounds. For smaller vessels, this assumption may be true to the extinct that the similar fishing grounds are within reach of their operating radius. However, it is hard to define when a value is lost for fishermen, and it is a wide question to answer. This subject is further discussed in the evaluation of prerequisite 4.

7.2.5 Prerequisite 4: When a fishing vessel travels to a similar fishing area, the increased competition in this area, will not lead to a smaller amount of catch value per vessel or increasing the time it takes to land the catch

As in many cases, an increased competition of scarce resources lead to less output. According to the fishermen interviewed in the report made by Mackinson et al. (2006), they argued that "*...if there is insufficient fish to support the increased fishing pressure, the outcome would be a reduced catch, with consequent loss of profit.*" Taking this to account it seems rather unlikely that the fishermen in local Træna with a limited operating radius, will be able to catch the same amount if the competition in popular fishing grounds increase. If this prerequisite do not hold, the development of wind farms will entail a further financial loss for the fishermen in the form of reduced catch value due to increased competition. A such financial loss will both impact the vessels owner and the fishermen. The owner of the vessel will decrease his income from catch value, and the fishermen paid through share-based remuneration schemes will receive a lower total income. Such a loss is possible to measure through our model, by inserting a loss variable linked to all value caught inside a specific fishing ground, as well as the closest similar fishing ground where the fishers now are forced to move to. Both the fishermen usually fishing inside the occupied fishing ground and the fishermen fishing in the replacement fishing ground will be affected by such a variable.

7.3 Limitations regarding data and input variables

7.3.1 Data

The most significant limitation regarding the data set is the number of years included. Fishing locations may vary drastically from year to year, and the results from a sample of only three years, may possibly be affected by annual individual incidents, that is not representative for normal fishing activity. As a measure to catch value stability within the three years, we plotted the percentage of catch value categorised by species distributed by years in the figures of appendix A0.2. These figures signal a relative stable catch activity within catch area 06-33 and 06-31, while there is a significant increase in 2019 in catch area 06-27, indicating this year might be an outlier compared to what is normal.

There are two reasons to why we did not include several more years of data. The first reason is the limit of computer power. The three years of position data merged by landing notes, lead to about 26M rows of data and our machine was at the breaking point when we performed the analysis. Secondly, the sample of vessels with position data will probably decrease the further back in time the data set is retrieved from, at least that is the the trend from the three years we have analysed. However, the model algorithm is generic, and with the right amount of computing power, there is no problem inserting data from earlier years. The model is perhaps a little ahead of its time and as the years go by and the proportion of vessels using tracking gear within the fleet rises further, it will be even more accurate and representative.

7.3.2 Input variables

Including the data sets, there were also four input variables that to some extent determined the results. First, we assumed the speed used while not fishing on average is ten knots and that this requires 75% of total engine capacity. This variable is directly linked to both additional labour per hour and the additional fuel costs. A higher average speed, would result in lower additional labour hours and higher amount of additional fuel costs. A way to increase the accuracy could be by inserting a *Top speed pr vessel* variable, but we were not able to obtain such information.

Secondly, we used the algorithm developed by The Food and Agriculture Organization (2020) in order to estimate the hourly consumption of fuel. The full explanation of this algorithm and input variables is found in figure A0.18. It is based on percentage of max engine used, the engine in horse powers, engine and fuel type and the consumption in grams/hp/hour. The consumption in grams/hp/hour is dependent on the engine type, and we assumed all vessels under 28 metres have a regular diesel engine while those larger than 28 metres have a diesel (turbo-charged) engine, with a lower consumption in grams/hp/hour than normal diesel engines. By computing wrong engine type to a specific vessel, the estimated fuel costs for a vessel could be either an overestimation or an underestimation. The vessel engine in horse powers is accurate on vessel level as this information is obtained from the landing notes. Since detours by large vessels ended up being the main driver for additional fuel costs, we contacted a Norwegian shipping company responsible for a large specific vessel with a high estimate of fuel per hour within the fleet, to ensure that the estimated litres per hour were not significantly inaccurate from reality. Our estimate was about 1200 litres per hour. They could assure that while moving in ten knots this was a rather accurate estimate. To ensure the anonymity of the vessel, we will not include it as a source. This is not to state that the estimate for every vessel is correct, but at least we can say that for the large vessels, we have probably not made a significant overestimation of consumption per hour.

The third input variable is the average crew pr year obtained from the profitability report made by DoF (2018). The figures are based on averages pr length groups and is not specified to individual vessels, which might lead to wrong estimations. However, they are averages, and we are operating by the total fleet, so it is probably a somewhat representative measure. Average crew is multiplied by the total hours pr detour and is a driver for additional labour hours.

The fourth input variable is the litre cost of fuel. For detours computed by data with coordinates, we have used the average price of diesel per month sold in Norway and linked this price to the month of the respective detour. For detours computed by data without coordinates, we used the average price of diesel between 2016 and 2019. The figures are retrieved from Statistics Norway (2020).

7.4 Assessment of the validity of using data with coordinates as a measure to estimate the location of value without coordinates

The method we have used to estimate the location of values without coordinates, has its potential weaknesses. Each vessel have their own fishing pattern and there is difficult to statistically prove the exact location to where the activity was conducted. As an example, say we estimate that among tracked vessels under 11 metres, 30% of the catch value of cod caught by yarns is evidently caught inside a wind farm. Among the non-tracked vessels under 11 metres, one vessel has a significantly large catch value of cod caught by yarns, but it did not conduct any fishing activity within a wind farm area. In this case, the method will overestimate the value caught inside the wind farm.

As a way to ensure that the value is somewhat distributed equally within each group, tracked and non-tracked vessels, we developed distribution plots with the percentage of value caught by tracked vessels within a catch area against the percentage of non-tracked vessels in the same catch area. We find a rather equal proportion between the two measures for each respective catch area (figure A0.14, A0.12, A0.14 and A0.17), that indicates equal distributions between the two groups. However, we find no efficient way to significantly ensure that the fishing patterns between the two groups are equal.

As a way to ensure that the values located by coordinates are not concentrated at one location, we created several heatmaps filtered by length group and fishing gear. In figure 7.1, we see Trænafjorden Sør and Nord marked in green polygons and the grey areas are areas described in DoF's coastal data as areas that are frequently used for fishing. In figure 7.2, we see a heatmap of value caught bu vessels under 15 metres nearby Træna. In figure 7.3, figure 7.1 and 7.2 merged, and in this figure we can see that the value is distributed across the map, and that the values correspond to where DoF assume fishing activity to take place. This both indicates that the value is not concentrated and that the model - combining AIS data to landing notes - seems accurate and credible.

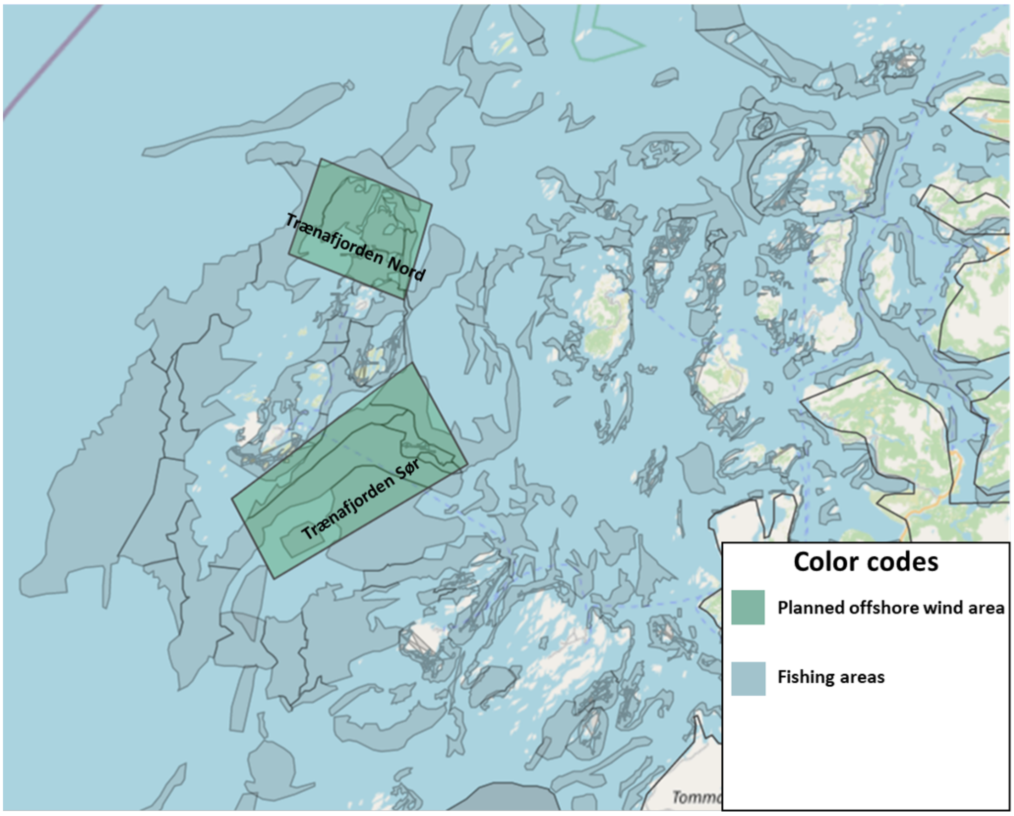


Figure 7.1: Trænafjorden and fishing areas marked in coastal data by DoF

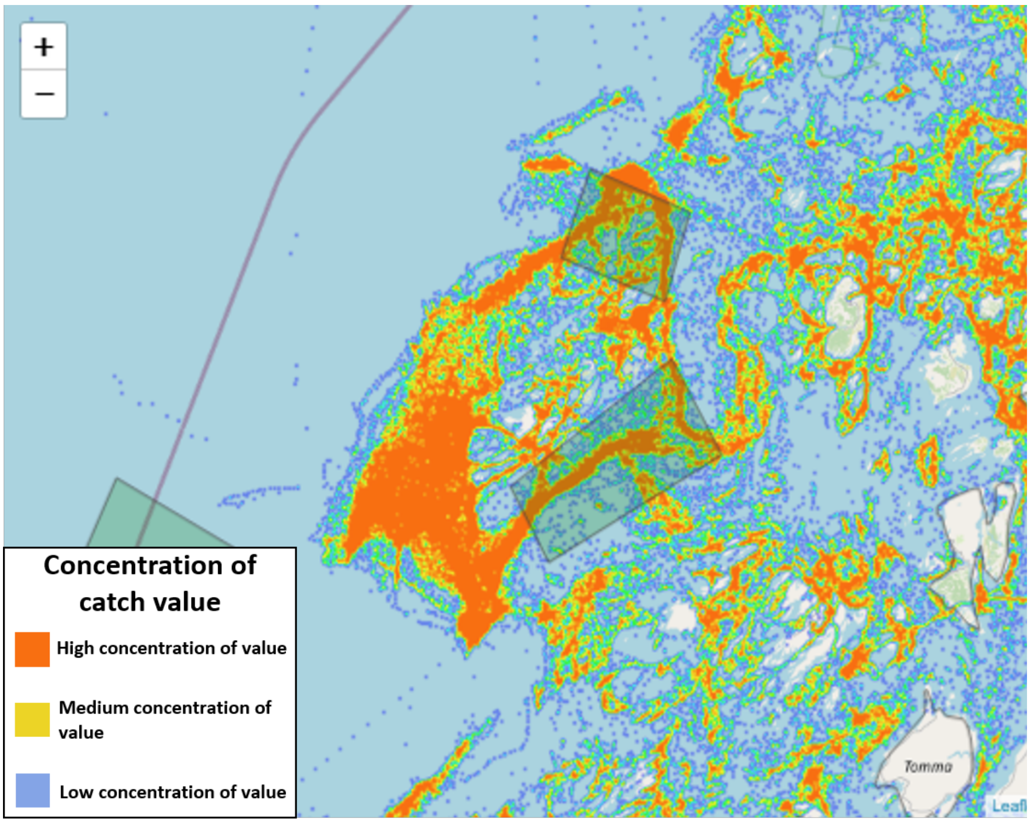


Figure 7.2: Distribution of catch value caught by vessels >15 metres near Træna. Heatmap based on concentration of catch value

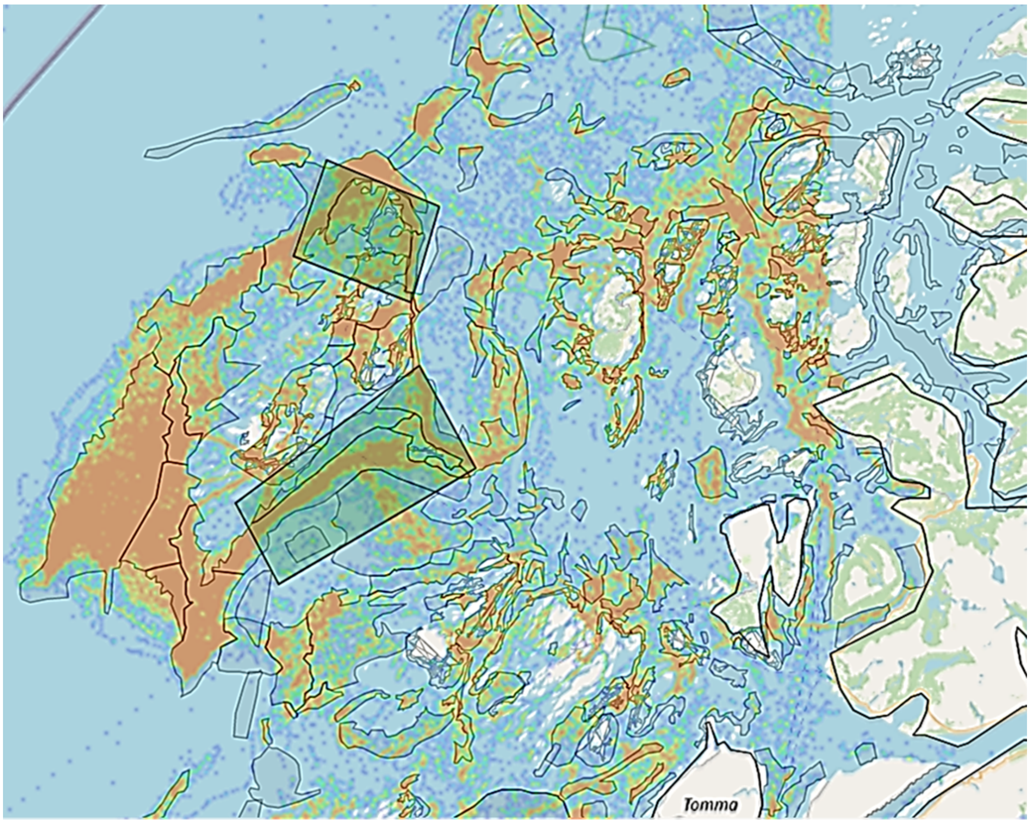


Figure 7.3: Distribution of catch value compared to fishing areas Figure 7.1 merged with figure 7.2

8 Conclusion

In this thesis, we have investigated the economic consequences of establishing offshore wind farms in Træna for the local community and the fleet operating in the respective areas.

In the literature review and directly through DoF, we discovered that the mainly applied methodology is qualitative, which is described as an issue, because this approach usually is time consuming and resource intensive. As a way to streamline the regular methodology, we have chosen to explore a different approach by creating a generic and fully quantitative model. The approach presented aims to locate catch value using position data and apply the distribution of this catch value on data without coordinates to create the best possible value estimate of specific areas, as well as using the position data to estimate detours and the following externalities of the detours.

We have through our method estimated the value of the fishing grounds inside the offshore wind areas Træna Vest, Trænafjorden Sør and Trænafjorden Nord, and their significance for the locals in Træna and fishermen in the area in general, as well as externalities brought on the commercial fishing industry by the development of offshore wind farms. We have considered the fishing grounds within Trænafjorden Sør and Nord to be moderately essential for the local population, whereas approximately 9 % of total catch value in their respective catch areas is caught within these offshore wind areas. Trænafjorden Sør entails the greatest impact on local fishermen, whereas the detours caused by occupying spatial areas in this fishing ground are estimated to entail up to 2000 labour hours in loss of opportunity costs over a period of three years. Subsequently, these detours may also lead to increased competition in local fishing grounds, which consequently entails reduced profits for the fishermen.

We have discovered that Træna Vest is an area for transit and that detours as a result of the offshore wind field can lead to an increase of fuel costs of NOK 12.6M, affecting large trawlers moving through the area. For both Træna Vest and Trænafjorden Sør, we have detected worst case scenarios by developing these offshore wind farms, that to severe degree will affect large pelagic trawlers fishing near Træna Vest and the local fishermen depending on the spawning grounds close to Trænafjorden Sør.

Our results suggest that the development of offshore wind in the targeted areas would lead to financial losses for a functioning industry, but it would probably not be completely destructive for the local fishing industry in an overall financial perspective. Further on, when the reason for impairing this industry - development of offshore wind - has not yet been documented as an industry that will be profitable in the long run for the Norwegian people, perhaps quite the contrary, a solution based on coexistence and a solution the fishermen accepts should in our opinion be emphasised heavily.

In this thesis, we aimed to develop a generic, quantitative model, to streamline the usual way of investigating issues related to fisheries and occupation of spatial areas at sea. The model we developed is applicable for future investigations and will in time increase its efficiency proportionally by the number of vessels using tracking gear. For now, we believe that the model can be applied for estimations, and that in the case of significant findings, one can supplement with qualitative surveys to strengthen the foundation of making decisions. Hopefully, our methodology can contribute to saving time and resources and be an inspiration to development of further quantitative approaches.

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Appendix

A Variables in the landing notes

Table A0.1: Variables in landing note part 1/3

Column headers (Norwegian)	Column headers (English)
Dokumentnummer	Document number
Dokumenttype (kode)	Document type (code)
Dokumenttype	Document type
Dokument versjonsnummer	Document version number
Dokument salgsdato	Document sales date
Dokument versjonstidspunkt	Document version time
Salgslag ID	Sales TeamID
Salgslag (kode)	Sales team (code)
Salgslag	Sales team
Mottaker ID	Recipient ID
Mottakernasjonalitet (kode)	Recipient nationality(code)
Mottakernasjonalitet	Recipient nationality
Mottaksstasjon	Reception station
Landingskommune (kode)	Landing municipality(code)
Landingskommune	Landing Municipality
Landingsfylke (kode)	Landing county(code)
Landingsfylke	Landing County
Landingsnasjon (kode)	Landing Nation(code)
Landingsnasjon	Landing Nation
Produksjonsanlegg	Production facilities
Produksjonskommune (kode)	Production municipality(code)
Produksjonskommune	Production municipality
Mottakende fartøy reg.merke	Receiving change registration field
Mottakende fartøy rkal	Receiving vessel rkal
Mottakende fartøytype (kode)	Receiving fibertype(code)
Mottakende fart.type	Receiving speed.type
Mottakende fartøynasj. (kode)	Receiving vessel nation.(Code)
Mottakende fart.nasj	Receiving fart.nasj
Fisker ID	FishermanID
Fiskerkommune (kode)	Fisheries municipality(code)
Fiskerkommune	Fisher municipality
Fiskernasjonalitet (kode)	Fishery nationality(code)
Fiskernasjonalitet	Fishery nationality
Fartøy ID	VesselID
Registreringsmerke (seddel)	Registration mark(note)
Kallesignal	Call signal
Fartøynavn	Vessel names
Fartøytype (kode)	Fiber type(code)
Fartøytype	Vessel type
Kvotefartøy reg.merke	Quota exchange registration mark
Besetning	Crew
Fartøykommune (kode)	Vessel municipality(code)
Fartøykommune	Vessel municipality

Table A0.2: Variables in landing note part 2/3

Column headers (Norwegian)	Column headers (English)
Fartøyfylke (kode)	Vessels ection(code)
Fartøyfylke	Vessel county
Fartøynasjonalitet (kode)	Vessel nationality (code)
Fartøynasjonalitet	Vessel nationality
Fartøynasjonalitet gruppe	Vessel nationality group
Lengde	Length
Lengdegruppe (kode)	Length group(code)
Lengdegruppe	Length group
Bruttotonnasje 1969	Gross tonnage 1969
Bruttotonnasje annen	Gross tonnage other
Byggeår	Year of construction
Ombyggingsår	Conversion year
Motorkraft	Engine power
Motorbyggeår	Engine year
Fangstår	Capture year
Siste fangstdato	Last Capture Date
Kvotetype (kode)	Quota type (code)
Kvotetype	Quota type
Redskap (kode)	Tools (code)
Redskap	Tools
Redskap - gruppe (kode)	Tools-group (code)
Redskap - gruppe	Tools-group
Redskap - hovedgruppe (kode)	Tools-main group
Redskap - hovedgruppe	Tools-main group
Fangstfelt (kode)	Catch field (code)
Kyst/hav (kode)	Coast/sea (code)
Hovedområde (kode)	Main area (code)
Hovedområde	Main area
Lon (hovedområde)	Lon (mainarea)
Lat (hovedområde)	Lat (mainarea)
Lokasjon (kode)	Location(code)
Lon (lokasjon)	Lon (location)
Lat (lokasjon)	Lat (location)
Sone (kode)	Zone (code)
Sone	Zone
Områdegruppering (kode)	Area grouping(code)
Områdegruppering	Area grouping
Hovedområde FAO (kode)	Main area FAO(code)
Hovedområde FAO	Main area FAO
Nord/sør for 62 grader nord	North/south for
Fangstdagbok (nummer)	Catch diary(number)
Fangstdagbok (turnummer)	Catch diary (turnnumber)
Landingsdato	Landing Date
Landingsklokkeslett	Landing time
Landingsmåned (kode)	Landing month(code)
Landingsmåned	Landing month
Landingstidspunkt	Landing time

Table A0.3: Variables in landing note part 3/3

Column headers (Norwegian)	Column headers (English)
Dellanding (signal)	Share of landing (signal)
Neste mottaksstasjon	Next receiving station
Forrige mottakstasjon	Previous receiving station
Linjenummer	Linen number
Art - FDIR (kode)	Art-FDIR (code)
Art - FDIR	Art-FDIR
Art (kode)	Art (code)
Art	Species
Art - gruppe (kode)	Art-group (code)
Art - gruppe	Art-group
Art - hovedgruppe (kode)	Species main group
Art - hovedgruppe	Species main group
Art FAO (kode)	ArtFAO (code)
Art FAO	ArtFAO
Produkttilstand (kode)	Product condition (code)
Produkttilstand	Product Condition
Konserveringsmåte (kode)	Preservation method (code)
Konserveringsmåte	Method of preservation
Landingsmåte (kode)	Landing method (code)
Landingsmåte	Landing method
Kvalitet (kode)	Quality (code)
Kvalitet	Quality
Størrelsesgruppering (kode)	Size grouping (code)
Anvendelse (kode)	Application (code)
Anvendelse	Application
Anvendelse hovedgruppe (kode)	Application maing roup (code)
Anvendelse hovedgruppe	Application main group
Antall stykk	Number of pieces
Bruttovekt	Gross weight
Produktvekt	Product weight
Produktvekt over kvote	Product weight over quota
Rundvekt over kvote	Round weight over quota
Rundvekt	Round weight
Enhetspris for kjøper	Unit price for buyer
Beløp for kjøper	Amount for buyer
Enhetspris for fisker	Unit price for fisherman
Beløp for fisker	Amount for fisherman
Støttebeløp	Aidamount
Lagsavgift	Teamfee
Inndradd fangstverdi	Confiscated catch value
Etterbetaling	Post payment
Fangstverdi	Catch value
Oppdateringstidspunkt	Update Time
Hovedomraade	Main Area
FangstID	CatchID
Timestamp	Timestamp

B Tools used to develop the model

In order to create the model and analyse its output, we used two software service tools, R and Microsoft Power BI (Power BI). R were mostly used while creating the model and Power BI for analysis.

A0.1 R

R is a free software program, mostly used for statistical computing, data science and visualisations (RProject, n.d.). It is an ideal program when handling large data sets and allows for a wide range of packages and functions, to perform advanced analysis (2019).

A0.1.1 Packages and functions

Most of our coding is used with so called, R base functions, that does not require any packages. However, to obtain the desired output, we had to use a few external packages.

The packages *rgdal*, *raster*, *rgeos*, *geosphere*, and *sp*, are all packages that perform functions related to geographics, maps and distances. From these packages, we used the following functions:

- **point.in.polygon:** Returns True/False whether a coordinate is inside a polygon.
- **Polygon/Polygons/SpatialPolygons:** Creates data frame of polygon for given coordinates.
- **distCosine:** Computes the shortest distance between two points, according to the 'law of the cosines'.

The package and function *sqldf* was also applied. It allows for values in one data frame to merge with values in another data frame, based on multiple criteria. Furthermore, the packages *dplyr* and *tidyr* were applied. They are packages containing functions that allows for basic data manipulation, such as ordering and filtering of data.

A0.2 Microsoft Power BI

Power BI is a software created by Microsoft, and is used to analyse and visualise large data sets (Wikipedia, 2020). The output from the model we created in R were data frames, and we used Power BI to link the data frames together and analyse their contents.

C Analysis and metrics of fleet and fishing activity designed in Power Bi and R

A0.1 Heatmap of fishing activity similar to what is inside of the wind farms

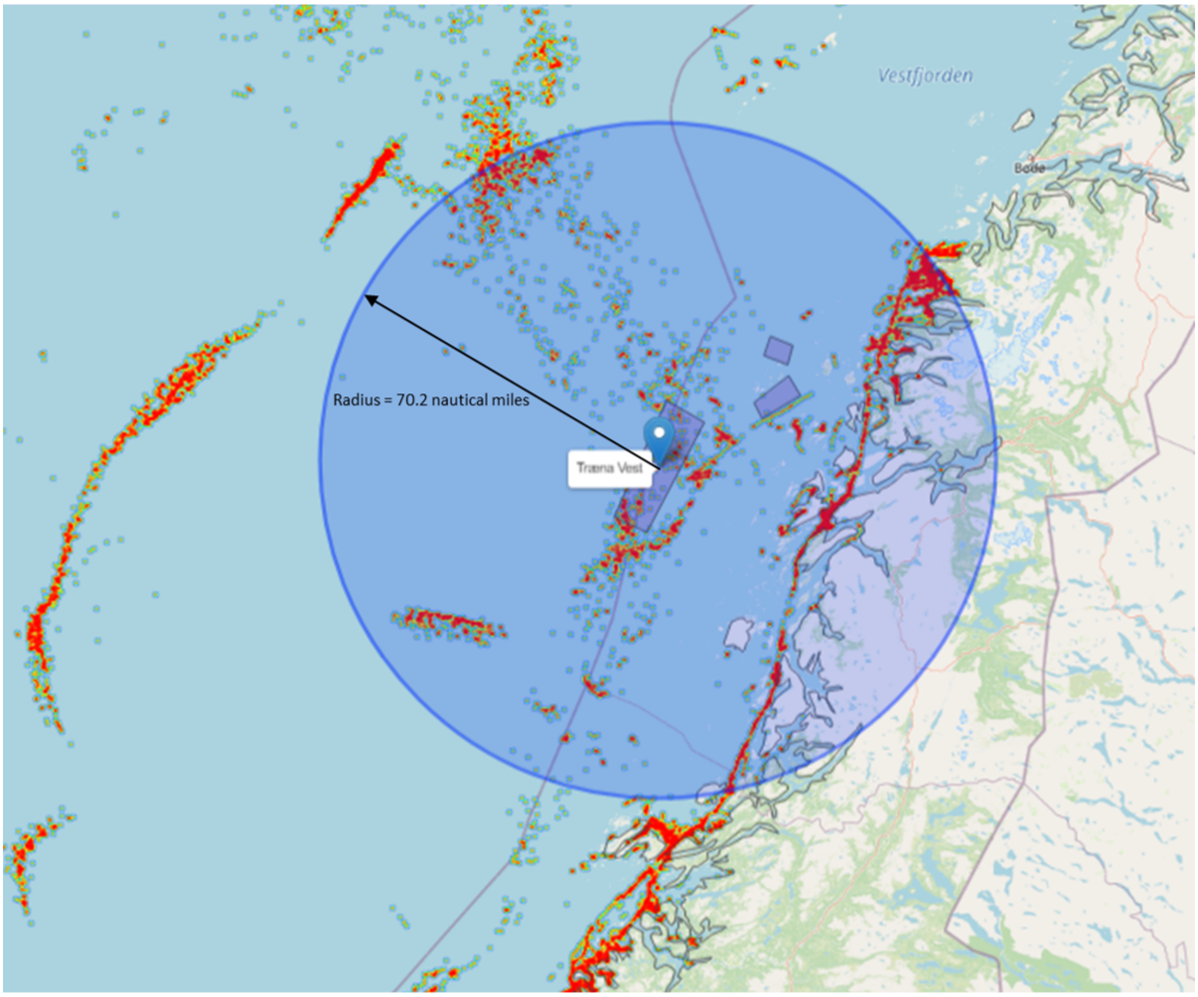


Figure A0.1: Heatmap of fishing activity similar to what is inside of Træna Vest. This is the category of fishing referred to as category 1 in table 5.3. The estimated detour to a similar fishing ground as what is inside the wind farm, is 70.2 nautical miles.

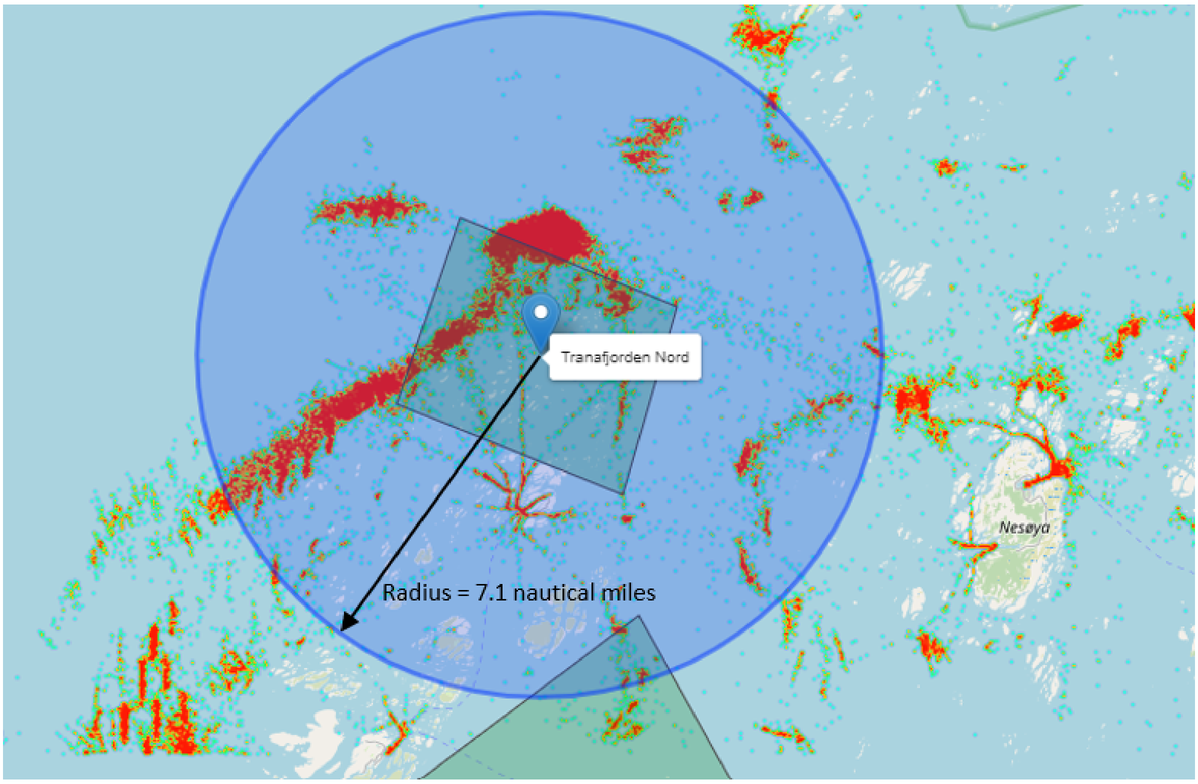


Figure A0.2: Heatmap of fishing activity similar to what is inside of Trænafjorden Nord.This is the category of fishing referred to as category 2 in table 5.3, filtered on fishing gear equals to yarns and pots.The estimated detour to a similar fishing ground as what is inside the wind farm, is 7.1 nautical miles.

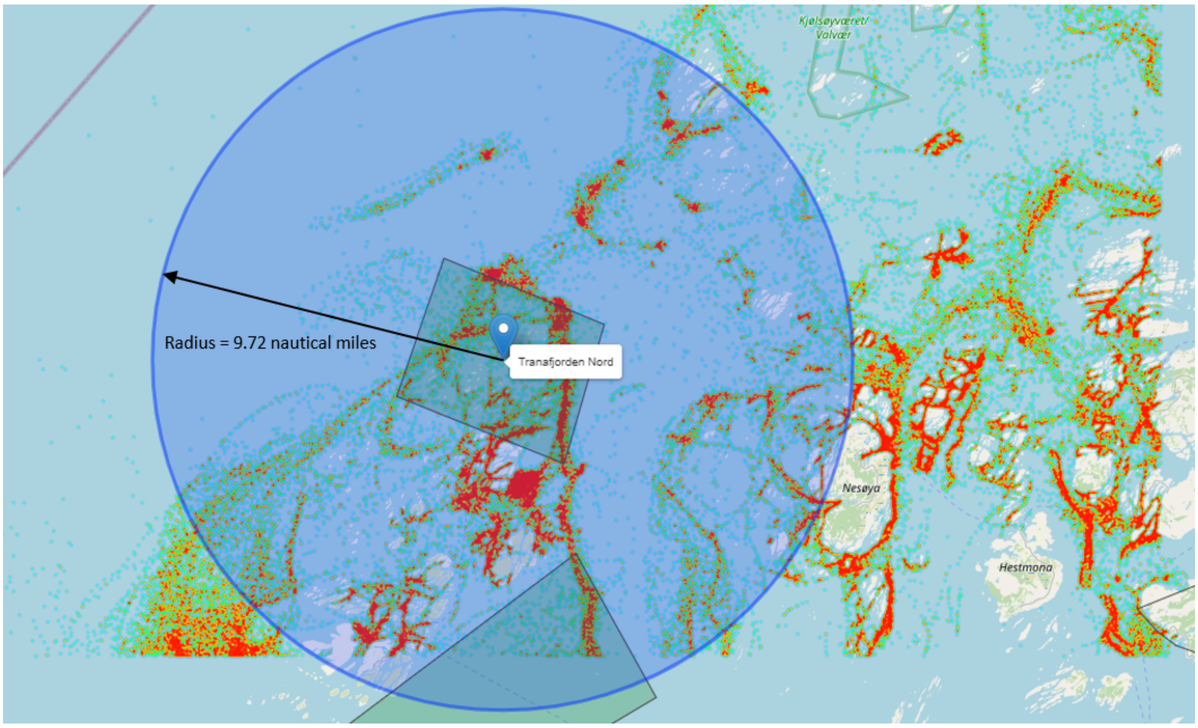


Figure A0.3: Heatmap of fishing activity similar to what is inside of Trænafjorden Nord.This is the category of fishing referred to as category 3 in table 5.3, filtered on fishing gear all but yarns and pots. The estimated detour to a similar fishing ground as what is inside the wind farm, is 9.7 nautical miles.

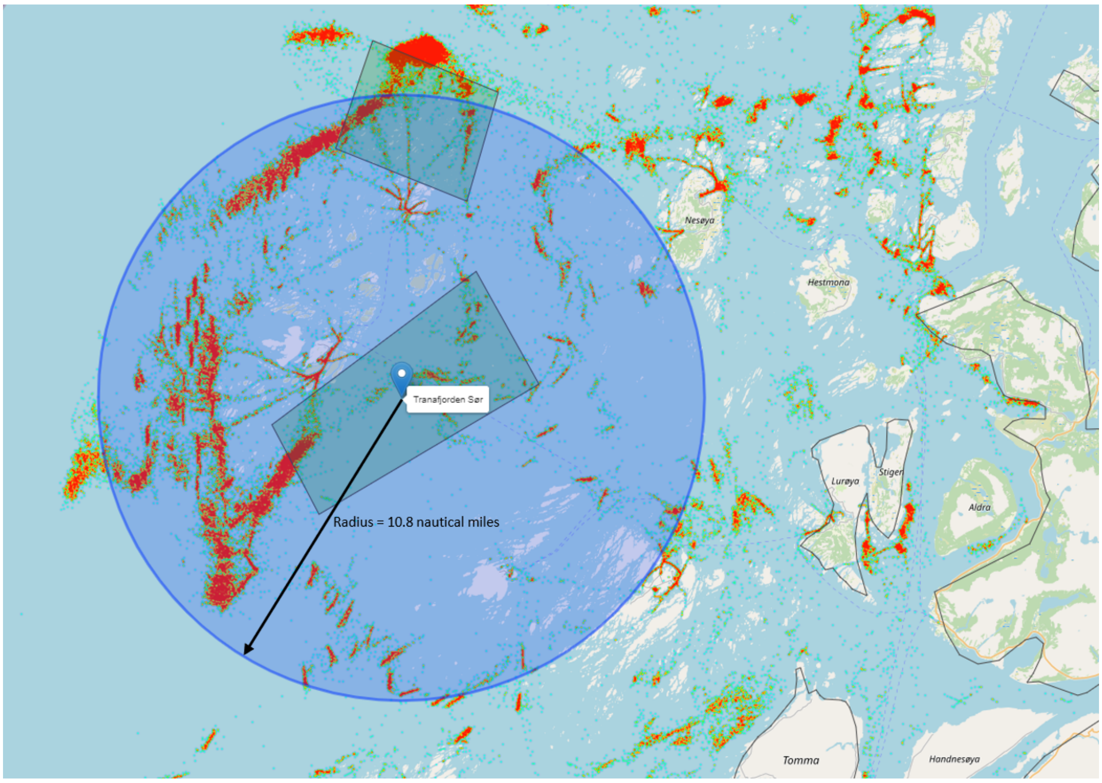


Figure A0.4: Heatmap of fishing activity similar to what is inside of Trænafjorden Sør.This is the category of fishing referred to as category 4 in table 5.3, filtered on fishing gear equals to yarns and pots.The estimated detour to a similar fishing ground as what is inside the wind farm, is 10.8 nautical miles.

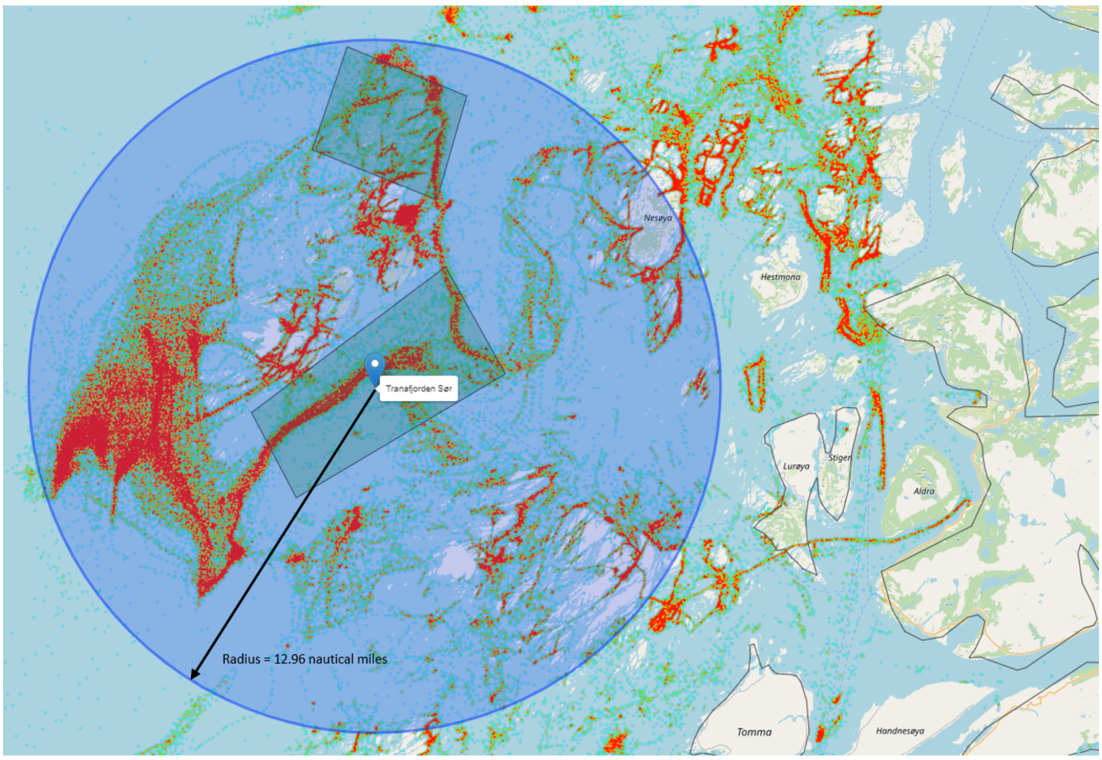


Figure A0.5: Heatmap of fishing activity similar to what is inside of Trænafjorden Sør.This is the category of fishing referred to as category 5 in table 5.3, filtered on fishing gear all but yarns and pots. The estimated detour to a similar fishing ground as what is inside the wind farm, is 12.96 nautical miles.

A0.2 Total fleet with and without coordinates

Table A0.1: Total fleet, no filter, based on data set with coordinates only, distributed in wind park areas and their respective catch areas. From top left: Træna Vest, catch area 06-27/06-26 separated | Træna Vest, catch area 06-27/06-26 joint | Trænafjorden Sør, catch area 06-33/06-31 joint| Trænafjorden Sør, catch area 06-33/06-31 separated | Trænafjorden Nord, catch area 06-31. Note that the counts of call signals are distinct counts of vessel IDs operating withing the catch areas. The columns are divided in "Outside wind park" and the respective wind park. The total sum looks smaller than what looks natural. That is because a distinct vessel can both be outside the wind park and inside it. Thus the total sum is the correct value of the distinct count of all vessels inside the catch area

Catch value and distinicit count of vessels related to Træna Vest | Divided in catch area and length group and activity inside and outside wind park

Catch area	06-26						06-27						Total	
Fishing location	Outside wind park		Trana Vest		Total		Outside wind park		Trana Vest		Total			
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**	**Value**	**Count of Call signal**
Under 11 m	0,00MNOK	1			**0,00MNOK**	**1**	8,06MNOK	56			**8,06MNOK**	**56**	**8,06MNOK**	**57**
11-14,99 m	0,01MNOK	1			**0,01MNOK**	**1**	27,97MNOK	22	0,06MNOK	2	**28,03MNOK**	**22**	**28,04MNOK**	**22**
15-20,99 m							4,48MNOK	4			**4,48MNOK**	**4**	**4,48MNOK**	**4**
21-27,99 m							16,89MNOK	17	0,01MNOK	1	**16,90MNOK**	**17**	**16,90MNOK**	**17**
28 m og over	24,96MNOK	28	5,13MNOK	12	**30,08MNOK**	**30**	72,26MNOK	61	16,16MNOK	26	**88,42MNOK**	**67**	**118,50MNOK**	**79**
Total	**24,97MNOK**	**30**	**5,13MNOK**	**12**	**30,10MNOK**	**32**	**129,66MNOK**	**160**	**16,23MNOK**	**29**	**145,89MNOK**	**166**	**175,99MNOK**	**179**

Catch value and distinicit count of vessels related to Træna Vest | Joint analysis of both 06-26 and 06-27

Fishing location	Outside wind park		Trana Vest		Total	
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**
Under 11 m	8,06MNOK	57			**8,06MNOK**	**57**
11-14,99 m	27,98MNOK	22	0,06MNOK	2	**28,04MNOK**	**22**
15-20,99 m	4,48MNOK	4			**4,48MNOK**	**4**
21-27,99 m	16,89MNOK	17	0,01MNOK	1	**16,90MNOK**	**17**
28 m og over	97,22MNOK	77	21,28MNOK	30	**118,50MNOK**	**79**
Total	**154,63MNOK**	**177**	**21,36MNOK**	**33**	**175,99MNOK**	**179**

Catch value and distinicit count of vessels related to Trænafjorden Sør | Joint analysis of both 06-31 and 06-33

Fishing location	Outside wind park		Tranafjorden Sør		Total	
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**
Under 11 m	28,99MNOK	454	0,43MNOK	32	**29,42MNOK**	**454**
11-14,99 m	40,85MNOK	135	4,41MNOK	21	**45,26MNOK**	**135**
15-20,99 m	2,17MNOK	5			**2,17MNOK**	**5**
21-27,99 m	0,52MNOK	2	0,67MNOK	2	**1,19MNOK**	**4**
28 m og over	2,48MNOK	10	0,06MNOK	2	**2,54MNOK**	**11**
Total	**75,02MNOK**	**606**	**5,56MNOK**	**57**	**80,58MNOK**	**609**

Catch value and distinicit count of vessels related to Trænafjorden Sør | Divided in catch area and length group and activity inside and outside wind park

Catch area	06-31						06-33						Total	
Fishing location	Outside wind park		Tranafjorden Sør		Total		Outside wind park		Tranafjorden Sør		Total			
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**	**Value**	**Count of Call signal**
Under 11 m	13,41MNOK	216	0,02MNOK	14	**13,43MNOK**	**216**	15,58MNOK	432	0,41MNOK	29	**15,99MNOK**	**432**	**29,42MNOK**	**454**
11-14,99 m	19,90MNOK	60	0,46MNOK	9	**20,37MNOK**	**62**	20,94MNOK	128	3,95MNOK	19	**24,89MNOK**	**128**	**45,26MNOK**	**135**
15-20,99 m	1,24MNOK	2			**1,24MNOK**	**2**	0,93MNOK	5			**0,93MNOK**	**5**	**2,17MNOK**	**5**
21-27,99 m	0,52MNOK	2	0,18MNOK	1	**0,70MNOK**	**3**			0,49MNOK	2	**0,49MNOK**	**2**	**1,19MNOK**	**4**
28 m og over	0,94MNOK	4			**0,94MNOK**	**4**	1,55MNOK	6	0,06MNOK	2	**1,60MNOK**	**8**	**2,54MNOK**	**11**
Total	**36,02MNOK**	**284**	**0,66MNOK**	**24**	**36,68MNOK**	**287**	**39,00MNOK**	**571**	**4,90MNOK**	**52**	**43,90MNOK**	**575**	**80,58MNOK**	**609**

Catch value and distinicit count of vessels related to Trænafjorden Nord | Divided in length group and activity inside and outside wind park

Catch area	06-31						Total	
Fishing location	Outside wind park		Tranafjorden Nord		Total			
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**	**Value**	**Count of Call signal**
Under 11 m	13,41MNOK	216	1,36MNOK	12	**14,77MNOK**	**216**	**14,77MNOK**	**216**
11-14,99 m	19,90MNOK	60	2,27MNOK	8	**22,18MNOK**	**60**	**22,18MNOK**	**60**
15-20,99 m	1,24MNOK	2			**1,24MNOK**	**2**	**1,24MNOK**	**2**
21-27,99 m	0,52MNOK	2			**0,52MNOK**	**2**	**0,52MNOK**	**2**
28 m og over	0,94MNOK	4			**0,94MNOK**	**4**	**0,94MNOK**	**4**
Total	**36,02MNOK**	**284**	**3,63MNOK**	**20**	**39,65MNOK**	**284**	**39,65MNOK**	**284**

Table A0.2: Total fleet and value caught inside catch areas, no filter, based on both data set with and without coordinates, distributed in catch areas. Note that the counts of call signals are distinct counts of vessel IDs operating withing the catch areas. The total column to the right is the count of distinct vessels operating in all catch areas.

Catch Area	06-26		06-27		06-31		06-33		**Total**	
Lenght Group	Value	Count of Call signal	Value	Count of Call signal	Value	Count of Call signal	Value	Count of Call signal	**Value**	**Count of Call signal**
Under 11 m	814 NOK	1	37 741 500 NOK	136	32 396 100 NOK	278	35 775 707 NOK	487	**105 914 120 NOK**	**594**
11-14,99 m	12 646 NOK	1	43 175 750 NOK	31	23 312 982 NOK	66	29 685 247 NOK	135	**96 186 625 NOK**	**148**
15-20,99 m			4 483 092 NOK	4	1 243 317 NOK	2	926 485 NOK	5	**6 652 894 NOK**	**6**
21-27,99 m			16 899 046 NOK	17	702 776 NOK	3	490 755 NOK	2	**18 092 577 NOK**	**19**
28 m og over	31 443 657 NOK	31	90 120 957 NOK	67	938 080 NOK	4	1 601 524 NOK	8	**124 104 218 NOK**	**79**
Total	**31 457 117 NOK**	**33**	**192 420 345 NOK**	**255**	**58 593 255 NOK**	**353**	**68 479 717 NOK**	**637**	**350 950 433 NOK**	**846**

A0.3 Fleet analysis and metrics

Table A0.3: In this table, Fish species ID used in the further figures are encoded

Species main group	SpeciesID
Pelagic fish	01
Cod and cod fish	02
Flatfish, other demersal fish and deep-sea fish	03
Cartilaginous fish	04
Shellfish, molluscs and echinoderms	05
Macroalgae (seaweed and kelp)	09

Table A0.4: In this table, Gear ID used in the further figures are encoded

Gear - group	Redskap - gruppe (kode)
Seine	1
Fish net/yarn	2
Hooks	3
Cage and ruse	4
Trawl	5
Danish seine	6
Harpoon/cannon	7
Other gear	8
Fish farming/unspecified	9

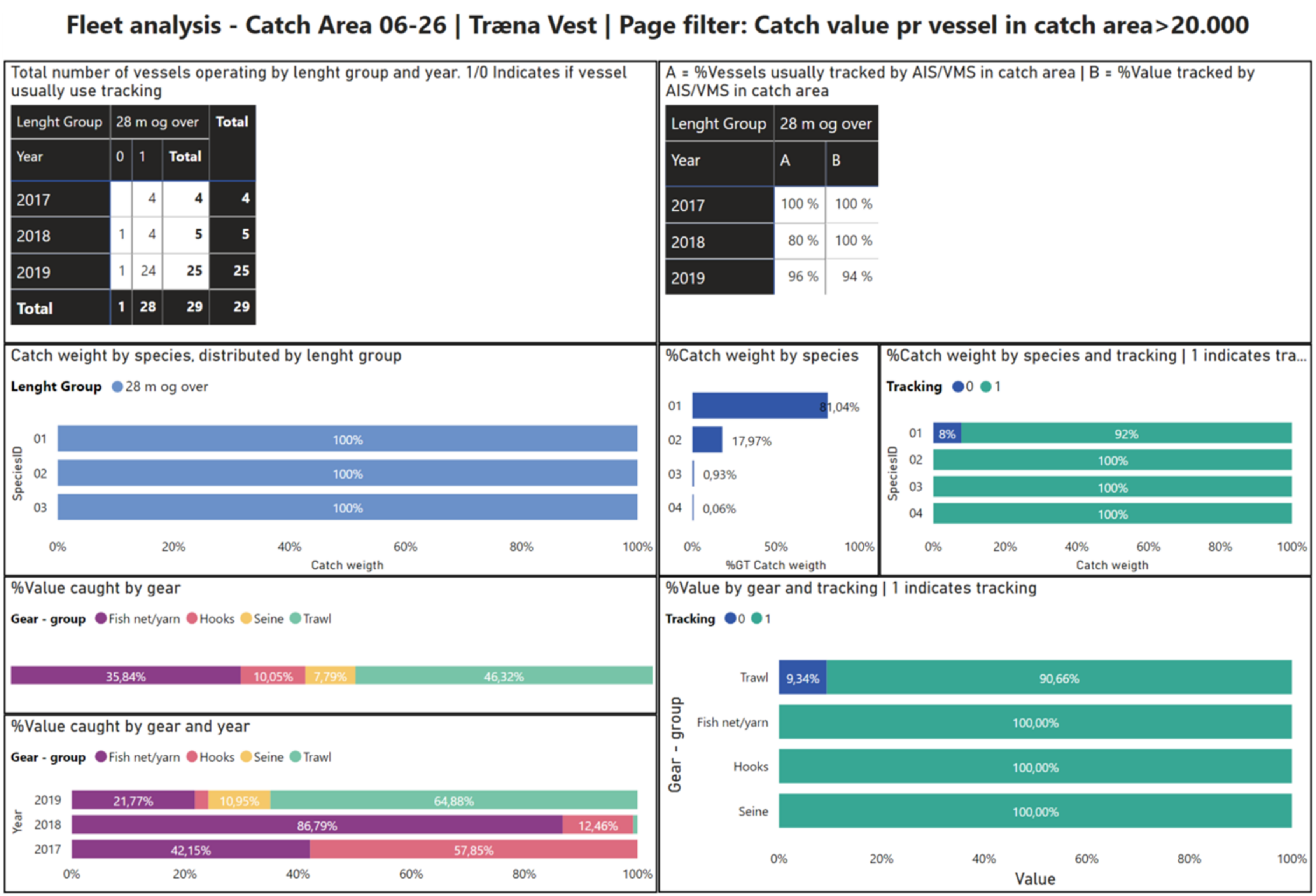


Figure A0.6: Fleet analysis: Catch area 06-26 | Træna Vest | Values are based on both data set with coordinates and without

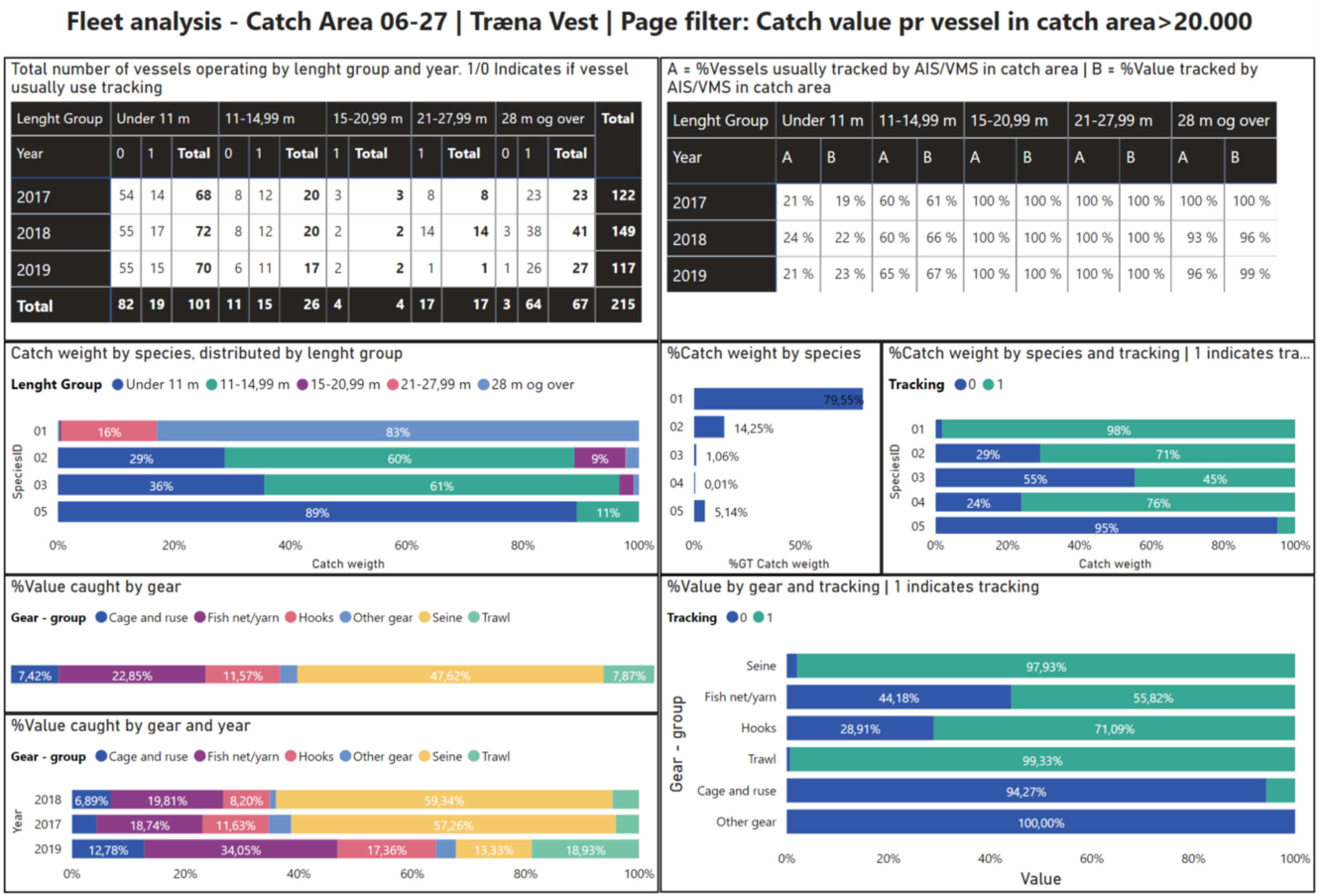
Catch weight and value by year and species

Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01			10059	43 029 NOK	3833332	15 609 246 NOK	3843391	15 652 276 NOK
02	246552	2 836 644 NOK	348076	5 129 757 NOK	331577	4 975 589 NOK	926204	12 941 991 NOK
03	15634	461 796 NOK	19141	602 603 NOK	13478	423 526 NOK	48254	1 487 925 NOK
Total	262186	3 298 440 NOK	377276	5 775 390 NOK	4178387	21 008 362 NOK	4817849	30 082 192 NOK

%Value and weight in wind park, compared to catch area total

Year	2018		2019	
SpeciesID	%Value in TranaVest	%weight in TranaVest	%Value in TranaVest	%weight in TranaVest
01	86,05 %	86,05 %	32,62 %	32,45 %
02	0,00 %	0,04 %	0,00 %	1,35 %
Total	0,64 %	2,33 %	24,23 %	29,88 %

Figure A0.7: Key measures regarding catch area 06-26 and Træna Vest wind park | The values are based on the data set with coordinates only



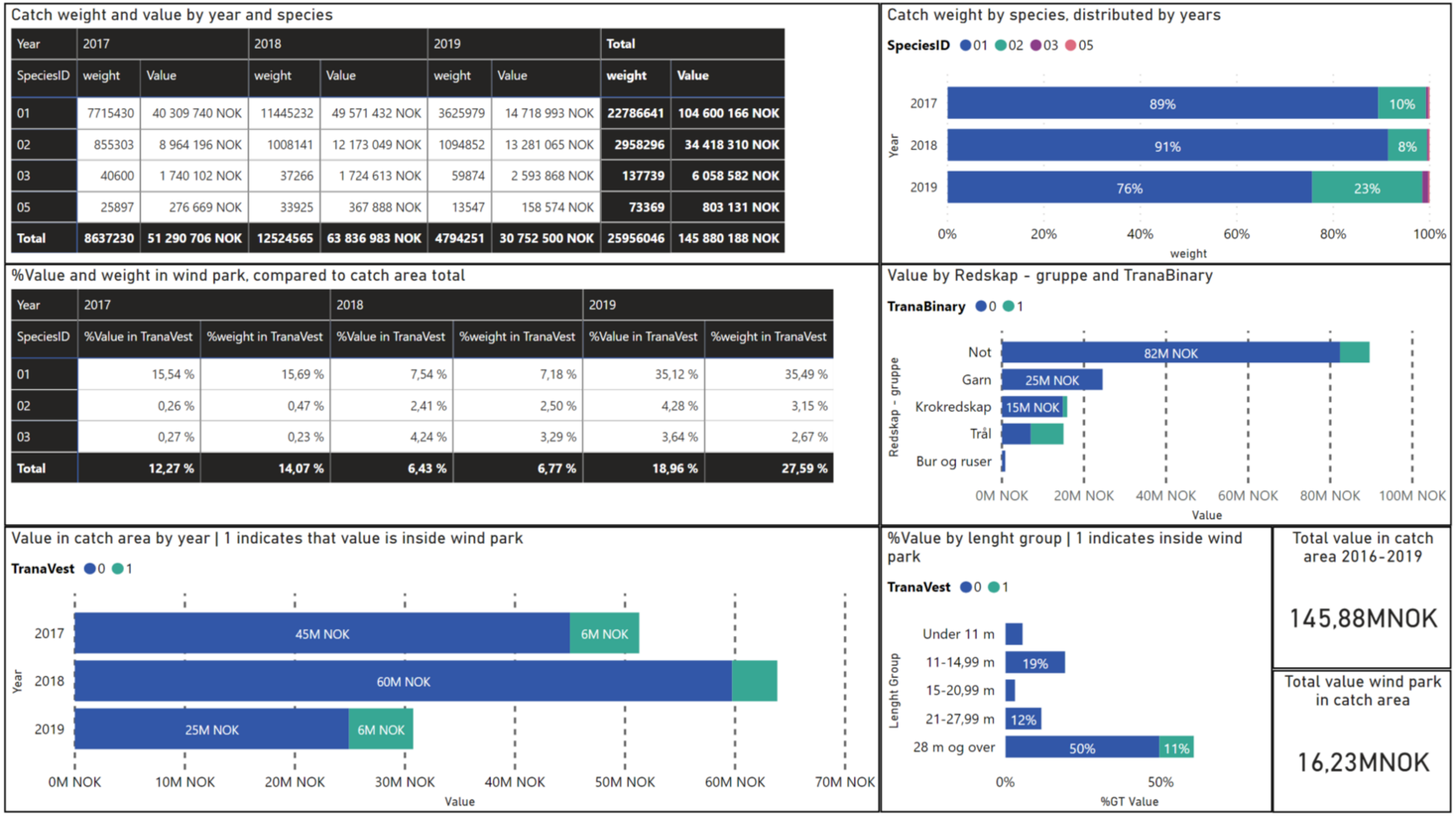
Total number of vessels operating by lenght group and year. 1/0 Indicates if vessel usually use tracking

Lenght Group	Under 11 m			11-14,99 m			15-20,99 m		21-27,99 m		28 m og over			Total
Year	0	1	Total	0	1	Total	1	Total	1	Total	0	1	Total	
2017	54	14	**68**	8	12	**20**	3	**3**	8	**8**		23	**23**	**122**
2018	55	17	**72**	8	12	**20**	2	**2**	14	**14**	3	38	**41**	**149**
2019	55	15	**70**	6	11	**17**	2	**2**	1	**1**	1	26	**27**	**117**
Total	**82**	**19**	**101**	**11**	**15**	**26**	**4**	**4**	**17**	**17**	**3**	**64**	**67**	**215**

A = %Vessels usually tracked by AIS/VMS in catch area | B = %Value tracked by AIS/VMS in catch area

Lenght Group	Under 11 m		11-14,99 m		15-20,99 m		21-27,99 m		28 m og over	
Year	A	B	A	B	A	B	A	B	A	B
2017	21 %	19 %	60 %	61 %	100 %	100 %	100 %	100 %	100 %	100 %
2018	24 %	22 %	60 %	66 %	100 %	100 %	100 %	100 %	93 %	96 %
2019	21 %	23 %	65 %	67 %	100 %	100 %	100 %	100 %	96 %	99 %

Figure A0.8: Fleet analysis: Catch area 06-27 | Træna Vest | Values are based on both data set with coordinates and without



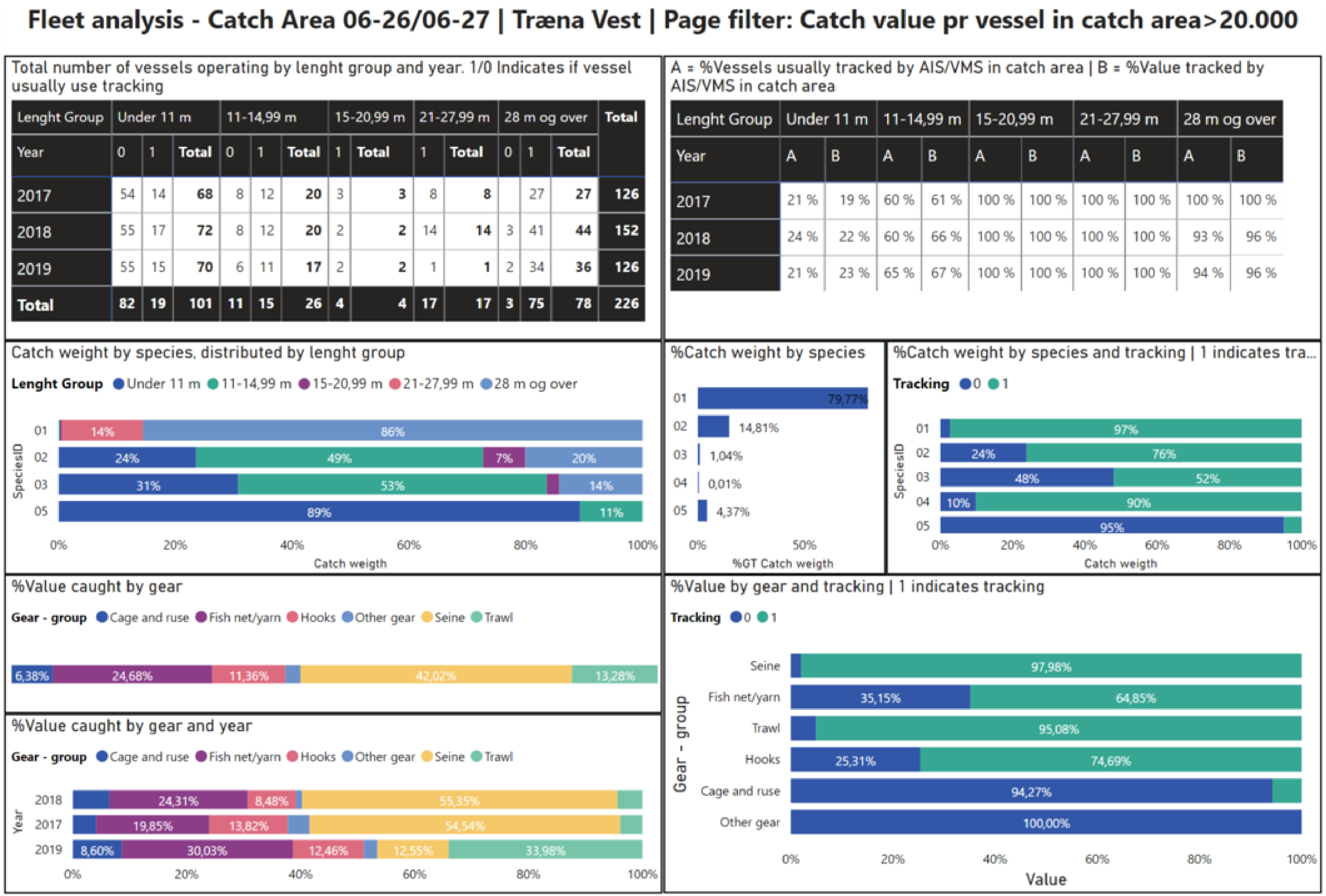
Catch weight and value by year and species

Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01	7715430	40 309 740 NOK	11445232	49 571 432 NOK	3625979	14 718 993 NOK	22786641	104 600 166 NOK
02	855303	8 964 196 NOK	1008141	12 173 049 NOK	1094852	13 281 065 NOK	2958296	34 418 310 NOK
03	40600	1 740 102 NOK	37266	1 724 613 NOK	59874	2 593 868 NOK	137739	6 058 582 NOK
05	25897	276 669 NOK	33925	367 888 NOK	13547	158 574 NOK	73369	803 131 NOK
Total	8637230	51 290 706 NOK	12524565	63 836 983 NOK	4794251	30 752 500 NOK	25956046	145 880 188 NOK

%Value and weight in wind park, compared to catch area total

Year	2017		2018		2019	
SpeciesID	%Value in TranaVest	%weight in TranaVest	%Value in TranaVest	%weight in TranaVest	%Value in TranaVest	%weight in TranaVest
01	15,54 %	15,69 %	7,54 %	7,18 %	35,12 %	35,49 %
02	0,26 %	0,47 %	2,41 %	2,50 %	4,28 %	3,15 %
03	0,27 %	0,23 %	4,24 %	3,29 %	3,64 %	2,67 %
Total	12,27 %	14,07 %	6,43 %	6,77 %	18,96 %	27,59 %

Figure A0.9: Key measures regarding catch area 06-27 and Træna Vest wind park | The values are based on the data set with coordinates only



Fleet analysis - Catch Area 06-26/06-27 | Træna Vest | Page filter: Catch value pr vessel in catch area>20.000

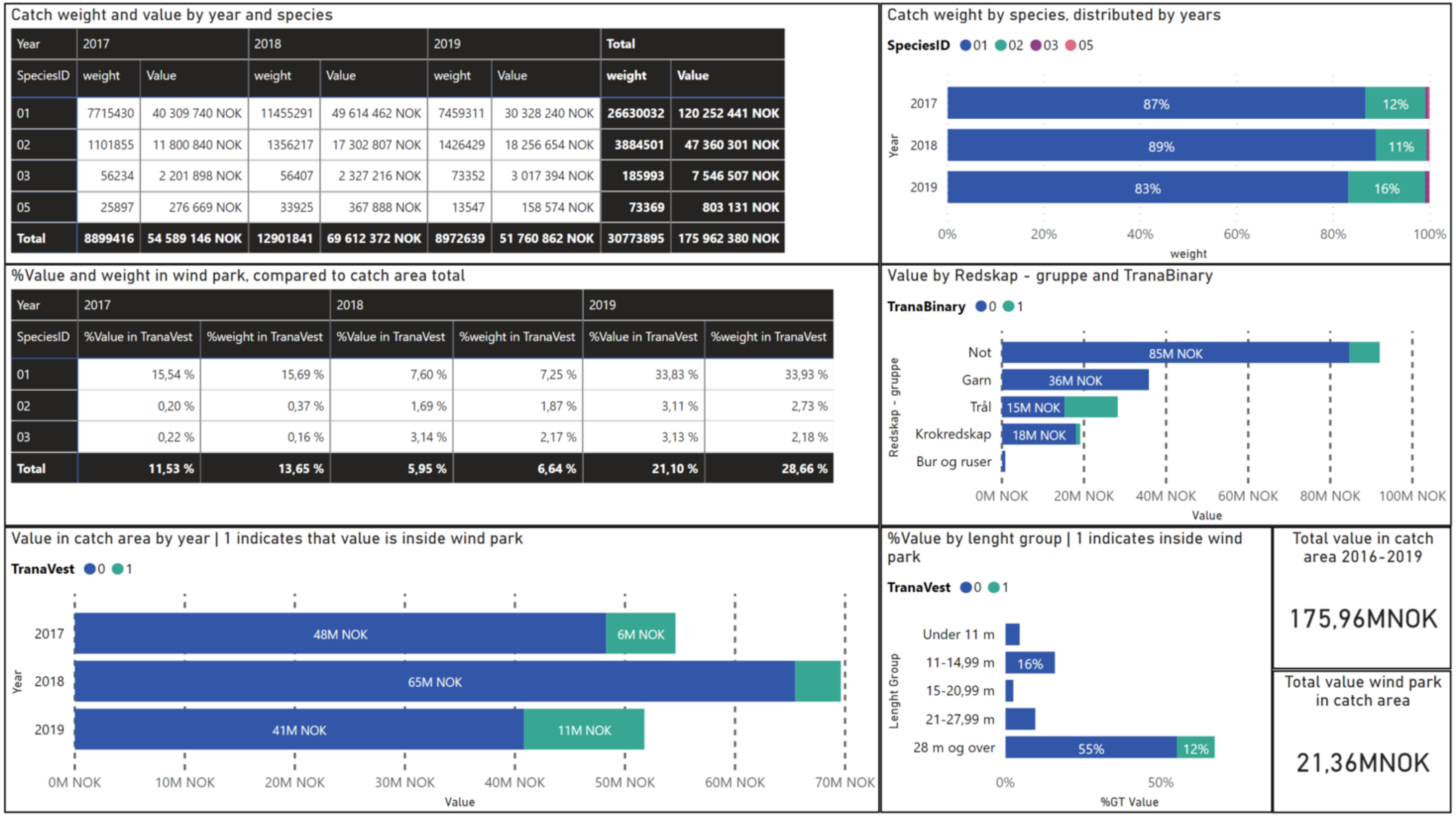
Total number of vessels operating by lenght group and year. 1/0 Indicates if vessel usually use tracking

Lenght Group	Under 11 m			11-14,99 m			15-20,99 m		21-27,99 m		28 m og over			Total
Year	0	1	Total	0	1	Total	1	Total	1	Total	0	1	Total	
2017	54	14	68	8	12	20	3	3	8	8		27	27	126
2018	55	17	72	8	12	20	2	2	14	14	3	41	44	152
2019	55	15	70	6	11	17	2	2	1	1	2	34	36	126
Total	82	19	101	11	15	26	4	4	17	17	3	75	78	226

A = %Vessels usually tracked by AIS/VMS in catch area | B = %Value tracked by AIS/VMS in catch area

Lenght Group	Under 11 m		11-14,99 m		15-20,99 m		21-27,99 m		28 m og over	
Year	A	B	A	B	A	B	A	B	A	B
2017	21 %	19 %	60 %	61 %	100 %	100 %	100 %	100 %	100 %	100 %
2018	24 %	22 %	60 %	66 %	100 %	100 %	100 %	100 %	93 %	96 %
2019	21 %	23 %	65 %	67 %	100 %	100 %	100 %	100 %	94 %	96 %

Figure A0.10: Fleet analysis: Joint analysis of catch area 06-26 and 06-27 | Træna Vest | Values are based on both data set with coordinates and without



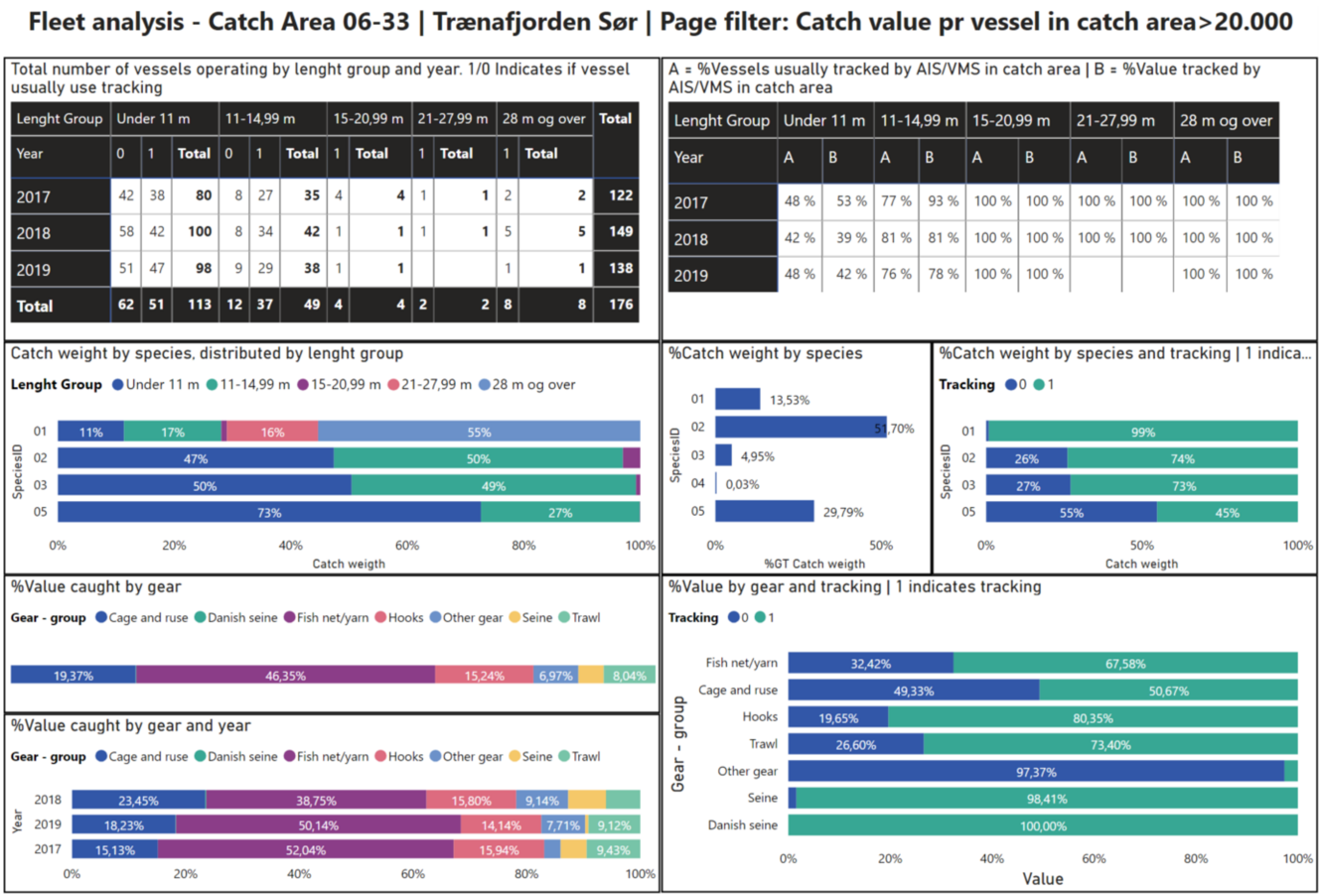
Catch weight and value by year and species

Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01	7715430	40 309 740 NOK	11455291	49 614 462 NOK	7459311	30 328 240 NOK	26630032	120 252 441 NOK
02	1101855	11 800 840 NOK	1356217	17 302 807 NOK	1426429	18 256 654 NOK	3884501	47 360 301 NOK
03	56234	2 201 898 NOK	56407	2 327 216 NOK	73352	3 017 394 NOK	185993	7 546 507 NOK
05	25897	276 669 NOK	33925	367 888 NOK	13547	158 574 NOK	73369	803 131 NOK
Total	8899416	54 589 146 NOK	12901841	69 612 372 NOK	8972639	51 760 862 NOK	30773895	175 962 380 NOK

%Value and weight in wind park, compared to catch area total

Year	2017		2018		2019	
SpeciesID	%Value in TranaVest	%weight in TranaVest	%Value in TranaVest	%weight in TranaVest	%Value in TranaVest	%weight in TranaVest
01	15,54 %	15,69 %	7,60 %	7,25 %	33,83 %	33,93 %
02	0,20 %	0,37 %	1,69 %	1,87 %	3,11 %	2,73 %
03	0,22 %	0,16 %	3,14 %	2,17 %	3,13 %	2,18 %
Total	11,53 %	13,65 %	5,95 %	6,64 %	21,10 %	28,66 %

Figure A0.11: Joint key measures regarding catch area 06-26 and 06-27 and Træna Vest wind park | The values are based on the data set with coordinates only



Fleet analysis - Catch Area 06-33 | Trænafjorden Sør | Page filter: Catch value pr vessel in catch area>20.000

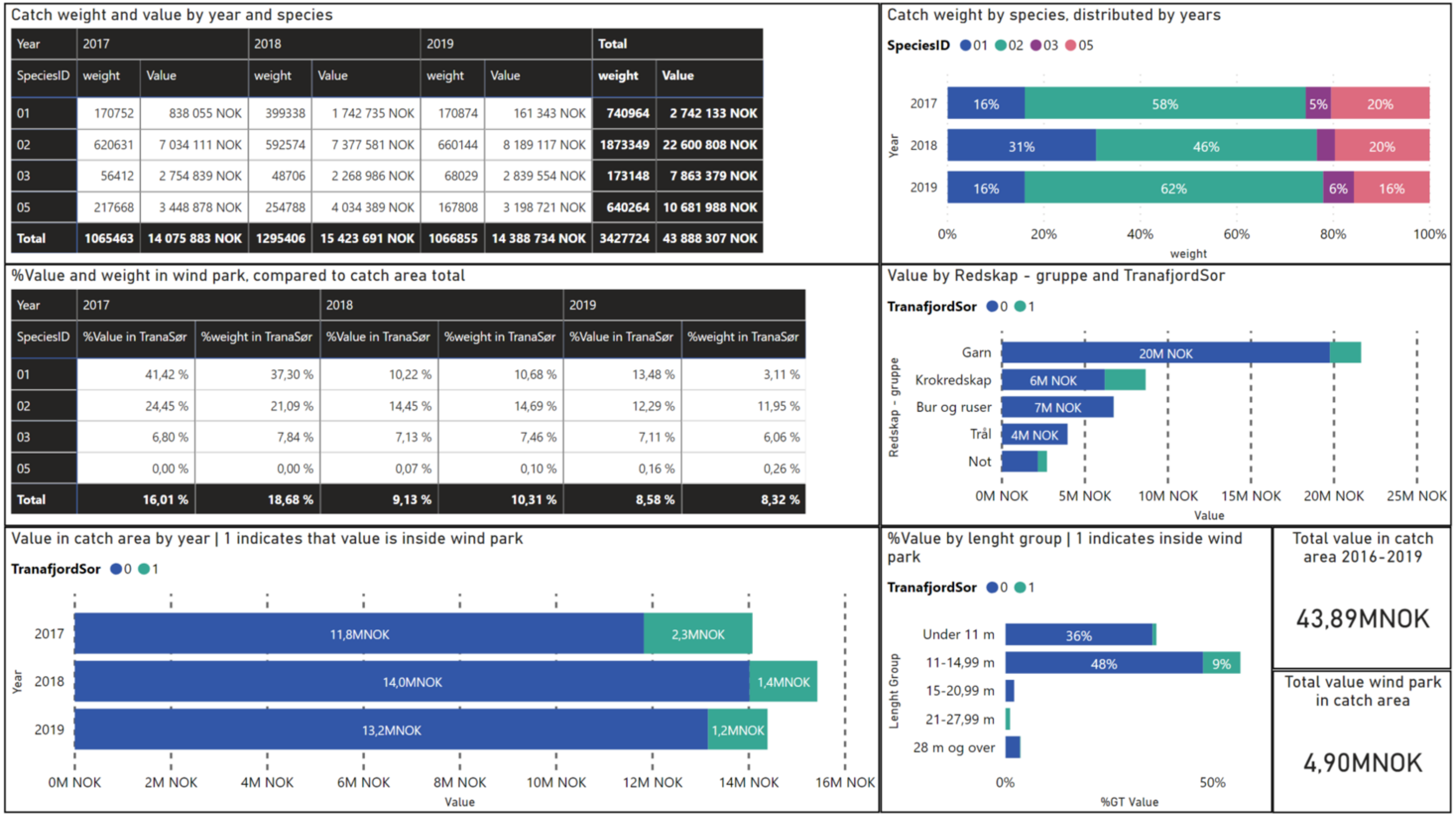
Total number of vessels operating by lenght group and year. 1/0 Indicates if vessel usually use tracking

Lenght Group	Under 11 m			11-14,99 m			15-20,99 m		21-27,99 m		28 m og over		Total
Year	0	1	Total	0	1	Total	1	Total	1	Total	1	Total	
2017	42	38	80	8	27	35	4	4	1	1	2	2	122
2018	58	42	100	8	34	42	1	1	1	1	5	5	149
2019	51	47	98	9	29	38	1	1			1	1	138
Total	62	51	113	12	37	49	4	4	2	2	8	8	176

A = %Vessels usually tracked by AIS/VMS in catch area | B = %Value tracked by AIS/VMS in catch area

Lenght Group	Under 11 m		11-14,99 m		15-20,99 m		21-27,99 m		28 m og over	
Year	A	B	A	B	A	B	A	B	A	B
2017	48 %	53 %	77 %	93 %	100 %	100 %	100 %	100 %	100 %	100 %
2018	42 %	39 %	81 %	81 %	100 %	100 %	100 %	100 %	100 %	100 %
2019	48 %	42 %	76 %	78 %	100 %	100 %			100 %	100 %

Figure A0.12: Fleet analysis: Catch area 06-33 | Trænafjorden Sør | Values are based on both data set with coordinates and without



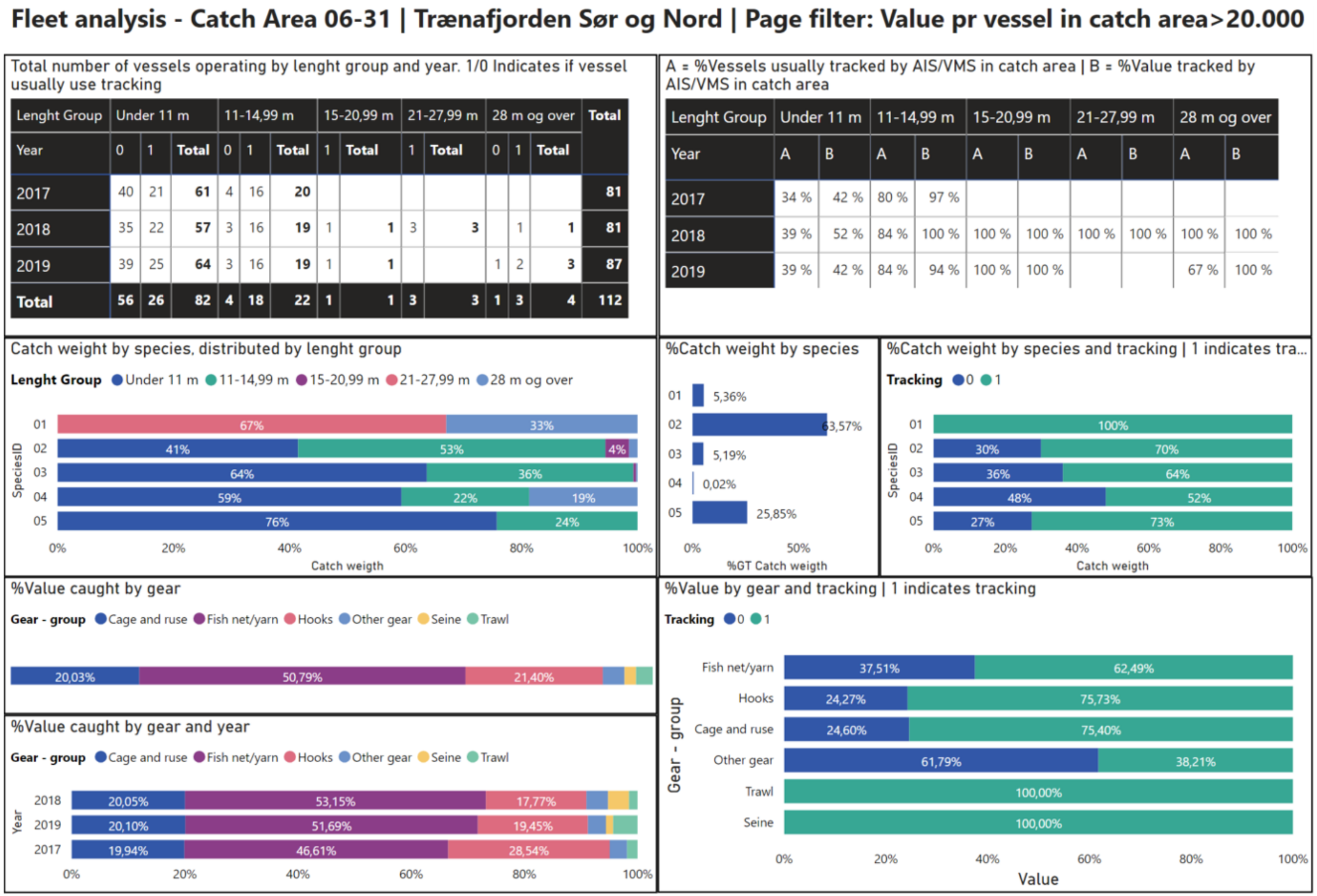
Catch weight and value by year and species

Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01	170752	838 055 NOK	399338	1 742 735 NOK	170874	161 343 NOK	740964	2 742 133 NOK
02	620631	7 034 111 NOK	592574	7 377 581 NOK	660144	8 189 117 NOK	1873349	22 600 808 NOK
03	56412	2 754 839 NOK	48706	2 268 986 NOK	68029	2 839 554 NOK	173148	7 863 379 NOK
05	217668	3 448 878 NOK	254788	4 034 389 NOK	167808	3 198 721 NOK	640264	10 681 988 NOK
Total	1065463	14 075 883 NOK	1295406	15 423 691 NOK	1066855	14 388 734 NOK	3427724	43 888 307 NOK

%Value and weight in wind park, compared to catch area total

Year	2017		2018		2019	
SpeciesID	%Value in TranaSør	%weight in TranaSør	%Value in TranaSør	%weight in TranaSør	%Value in TranaSør	%weight in TranaSør
01	41,42 %	37,30 %	10,22 %	10,68 %	13,48 %	3,11 %
02	24,45 %	21,09 %	14,45 %	14,69 %	12,29 %	11,95 %
03	6,80 %	7,84 %	7,13 %	7,46 %	7,11 %	6,06 %
05	0,00 %	0,00 %	0,07 %	0,10 %	0,16 %	0,26 %
Total	16,01 %	18,68 %	9,13 %	10,31 %	8,58 %	8,32 %

Figure A0.13: Key measures regarding catch area 06-33 and Trænafjorden Sør wind park | The values are based on the data set with coordinates only



Lenght Group	Under 11 m			11-14,99 m			15-20,99 m		21-27,99 m		28 m og over			Total
Year	0	1	Total	0	1	Total	1	Total	1	Total	0	1	Total	
2017	40	21	61	4	16	20								81
2018	35	22	57	3	16	19	1	1	3	3		1	1	81
2019	39	25	64	3	16	19	1	1			1	2	3	87
Total	56	26	82	4	18	22	1	1	3	3	1	3	4	112

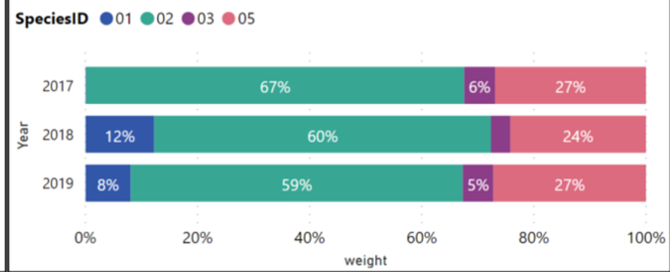
Lenght Group	Under 11 m		11-14,99 m		15-20,99 m		21-27,99 m		28 m og over	
Year	A	B	A	B	A	B	A	B	A	B
2017	34 %	42 %	80 %	97 %						
2018	39 %	52 %	84 %	100 %	100 %	100 %	100 %	100 %	100 %	100 %
2019	39 %	42 %	84 %	94 %	100 %	100 %			67 %	100 %

Figure A0.14: Fleet analysis: Catch area 06-31 | Trænafjorden Sør and Nord | Values are based on both data set with coordinates and without

Catch weight and value by year and species

Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01	1446	14 919 NOK	169802	711 809 NOK	88084	324 115 NOK	259332	1 050 844 NOK
02	610636	6 013 153 NOK	830789	9 265 805 NOK	644747	7 447 463 NOK	2086171	22 726 422 NOK
03	50084	1 829 849 NOK	47563	1 799 789 NOK	59588	1 876 171 NOK	157234	5 505 808 NOK
05	243861	2 814 127 NOK	334722	4 062 977 NOK	296276	4 147 231 NOK	874858	11 024 335 NOK
Total	906027	10 672 049 NOK	1382876	15 840 380 NOK	1088694	13 794 979 NOK	3377597	40 307 408 NOK

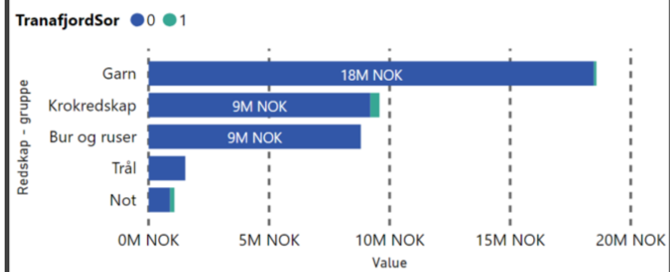
Catch weight by species, distributed by years



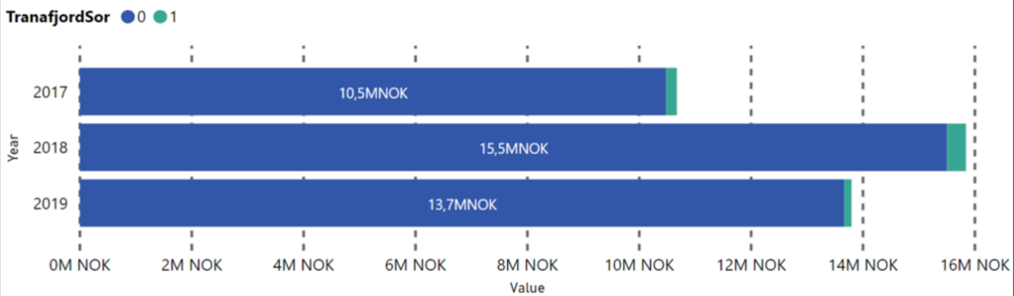
%Value and weight in wind park, compared to catch area total

Year	2017		2018		2019	
SpeciesID	%Value in TranaSør	%weight in TranaSør	%Value in TranaSør	%weight in TranaSør	%Value in TranaSør	%weight in TranaSør
01			25,02 %	25,12 %		
02	2,85 %	2,70 %	1,44 %	1,44 %	1,43 %	1,48 %
03	1,13 %	1,03 %	1,50 %	1,32 %	1,33 %	1,13 %
05			0,00 %	0,00 %	0,01 %	0,01 %
Total	1,80 %	1,88 %	2,13 %	4,00 %	0,96 %	0,94 %

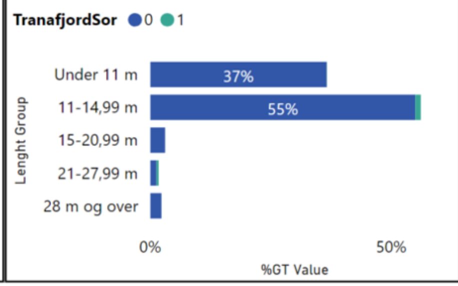
Value by Redskap - gruppe and TranafjordSor



Value in catch area by year | 1 indicates that value is inside wind park



%Value by lenght group | 1 indicates inside wind park



Total value in catch area 2016-2019

40,31MNOK

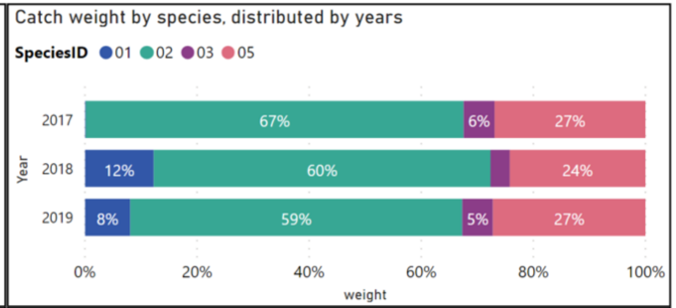
Total value wind park in catch area

662,21KNOK

Figure A0.15: Key measures regarding catch area 06-31 and Trænafjorden Sør wind park | The values are based on the data set with coordinates only

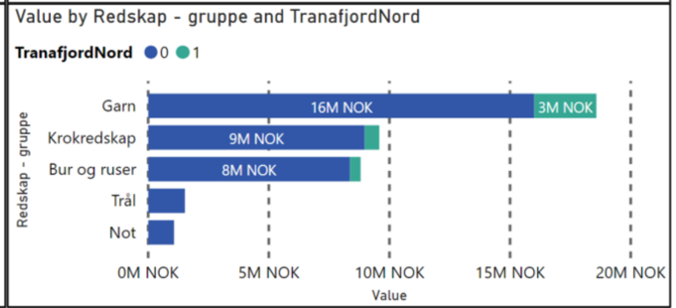
Catch weight and value by year and species

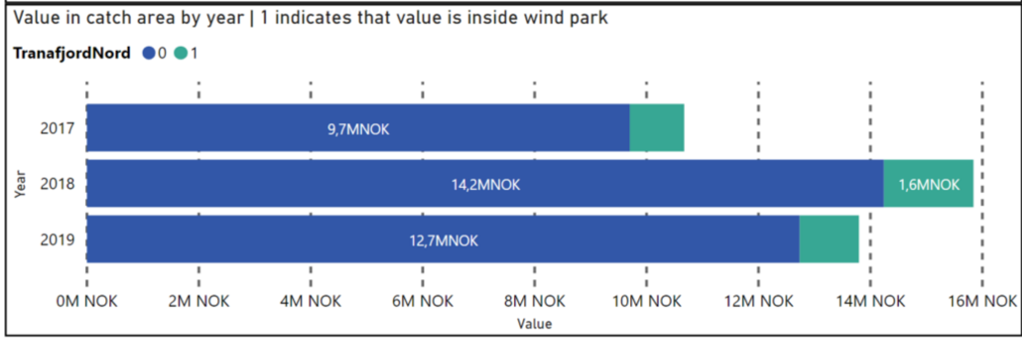
Year	2017		2018		2019		Total	
SpeciesID	weight	Value	weight	Value	weight	Value	weight	Value
01	1446	14 919 NOK	169802	711 809 NOK	88084	324 115 NOK	259332	1 050 844 NOK
02	610636	6 013 153 NOK	830789	9 265 805 NOK	644747	7 447 463 NOK	2086171	22 726 422 NOK
03	50084	1 829 849 NOK	47563	1 799 789 NOK	59588	1 876 171 NOK	157234	5 505 808 NOK
05	243861	2 814 127 NOK	334722	4 062 977 NOK	296276	4 147 231 NOK	874858	11 024 335 NOK
Total	906027	10 672 049 NOK	1382876	15 840 380 NOK	1088694	13 794 979 NOK	3377597	40 307 408 NOK

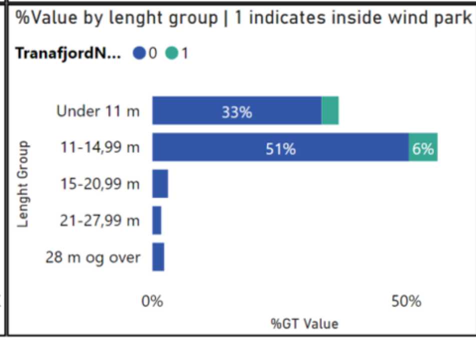


%Value and weight in wind park, compared to catch area total

Year	2017		2018		2019	
SpeciesID	%Value in TranaNord	%weight in TranaNord	%Value in TranaNord	%weight in TranaNord	%Value in TranaNord	%weight in TranaNord
02	9,75 %	8,28 %	12,90 %	11,66 %	9,85 %	8,93 %
03	11,16 %	8,64 %	15,25 %	14,79 %	9,75 %	9,55 %
05	6,46 %	7,18 %	3,21 %	3,49 %	3,42 %	4,11 %
Total	9,11 %	7,99 %	10,10 %	8,36 %	7,67 %	6,93 %







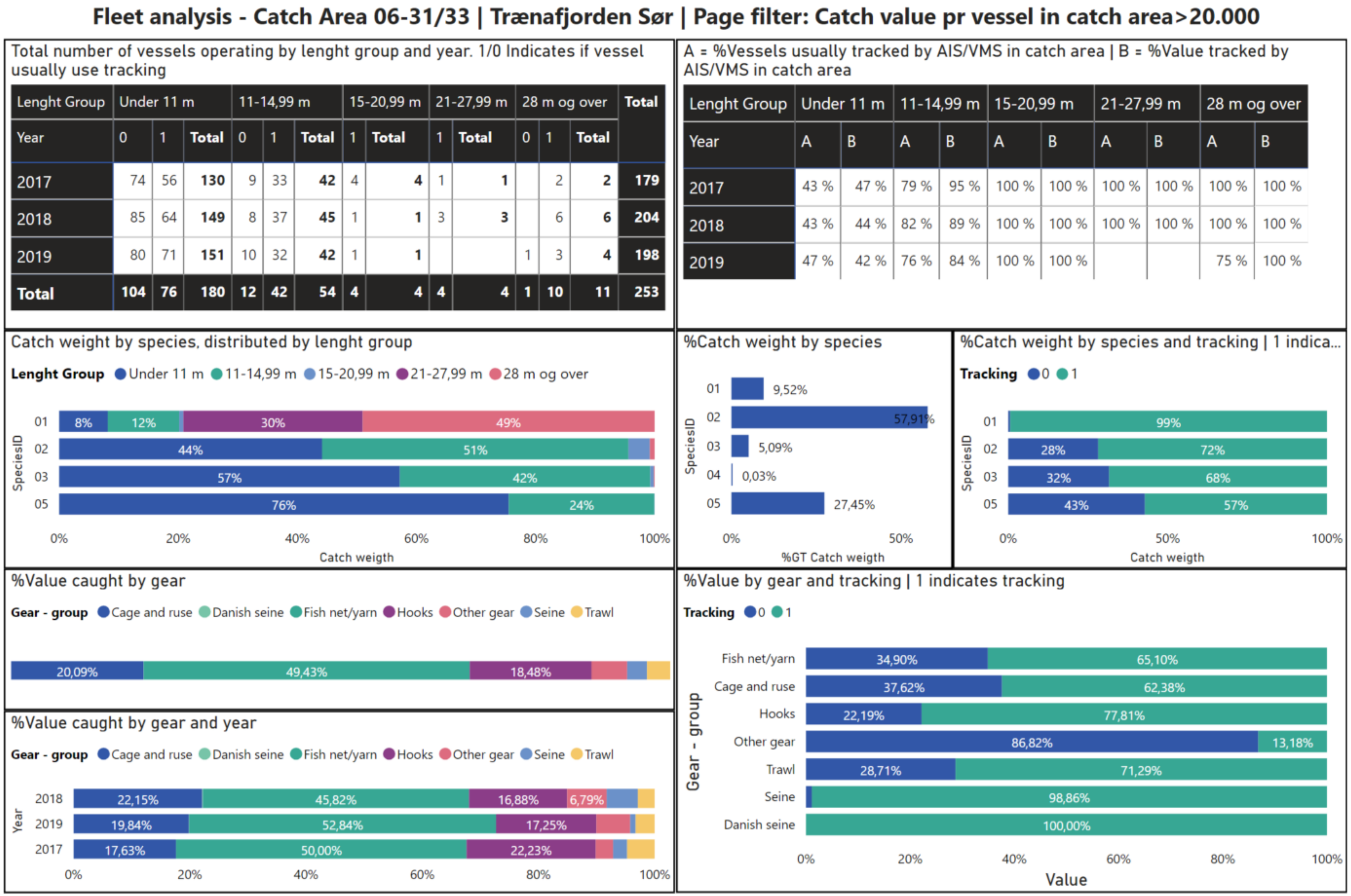
Total value in catch area 2016-2019

40,31MNOK

Total value wind park in catch area

3,63MNOK

Figure A0.16: Key measures regarding catch area 06-31 and Trænafjorden Nord wind park | The values are based on the data set with coordinates only



Fleet analysis - Catch Area 06-31/33 | Trænafjorden Sør | Page filter: Catch value pr vessel in catch area>20.000

Total number of vessels operating by lenght group and year. 1/0 Indicates if vessel usually use tracking

Lenght Group	Under 11 m			11-14,99 m			15-20,99 m		21-27,99 m		28 m og over			Total
Year	0	1	Total	0	1	Total	1	Total	1	Total	0	1	Total	
2017	74	56	**130**	9	33	**42**	4	**4**	1	**1**		2	**2**	**179**
2018	85	64	**149**	8	37	**45**	1	**1**	3	**3**		6	**6**	**204**
2019	80	71	**151**	10	32	**42**	1	**1**			1	3	**4**	**198**
Total	**104**	**76**	**180**	**12**	**42**	**54**	**4**	**4**	**4**	**4**	**1**	**10**	**11**	**253**

A = %Vessels usually tracked by AIS/VMS in catch area | B = %Value tracked by AIS/VMS in catch area

Lenght Group	Under 11 m		11-14,99 m		15-20,99 m		21-27,99 m		28 m og over	
Year	A	B	A	B	A	B	A	B	A	B
2017	43 %	47 %	79 %	95 %	100 %	100 %	100 %	100 %	100 %	100 %
2018	43 %	44 %	82 %	89 %	100 %	100 %	100 %	100 %	100 %	100 %
2019	47 %	42 %	76 %	84 %	100 %	100 %			75 %	100 %

Figure A0.17: Fleet analysis: Catch area 06-31/06-33 joint | Trænafjorden Sør | Values are based on both data set with coordinates and without

A0.4 Calculation of valuation

Table A0.5: Valuation: Træna Vest

Year	Wind park	Catch area	Species	Lenght Group	Total value catch area no tracing	% og value inside wind park	Estimated value wind park no tracing	Value of wind park tracing only	Total value of wind park	AIS/VMS
2017	Trana Vest	06-27	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	1 311 959 NOK	0,42 %	5 485 NOK	4 738 NOK	10 223 NOK	46,90 %
2017	Trana Vest	06-27	Torsk og torskeartet fisk	11-14,99 m	2 991 092 NOK	0,42 %	12 420 NOK	23 140 NOK	35 560 NOK	72,51 %
2017	Trana Vest	06-27	Pelagisk fisk	28 m og over	0 NOK	17,80 %	0 NOK	6 265 493 NOK	6 265 493 NOK	100,00 %
2018	Trana Vest	06-27	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	1 813 676 NOK	0,42 %	7 564 NOK	5 359 NOK	12 923 NOK	47,59 %
2018	Trana Vest	06-27	Torsk og torskeartet fisk	11-14,99 m	2 620 310 NOK	0,36 %	9 440 NOK	30 847 NOK	40 287 NOK	75,31 %
2018	Trana Vest	06-27	Pelagisk fisk	21-27,99 m	0 NOK	0,09 %	0 NOK	10 990 NOK	10 990 NOK	100,00 %
2018	Trana Vest	06-26	Pelagisk fisk	28 m og over	0 NOK	86,05 %	0 NOK	37 025 NOK	37 025 NOK	100,00 %
2018	Trana Vest	06-27	Bruskfisk (haifisk, skater, rokker og havmus)	28 m og over	0 NOK	100,00 %	0 NOK	2 044 NOK	2 044 NOK	100,00 %
2018	Trana Vest	06-27	Flatfisk, annen bunnfisk og dypvannsfisk	28 m og over	0 NOK	100,00 %	0 NOK	67 823 NOK	67 823 NOK	100,00 %
2018	Trana Vest	06-27	Pelagisk fisk	28 m og over	1 587 440 NOK	9,96 %	158 116 NOK	3 724 571 NOK	3 882 687 NOK	95,95 %
2018	Trana Vest	06-27	Torsk og torskeartet fisk	28 m og over	0 NOK	99,78 %	0 NOK	262 410 NOK	262 410 NOK	100,00 %
2019	Trana Vest	06-26	Pelagisk fisk	28 m og over	1 359 984 NOK	32,62 %	443 568 NOK	5 091 062 NOK	5 534 630 NOK	92,15 %
2019	Trana Vest	06-27	Bruskfisk (haifisk, skater, rokker og havmus)	28 m og over	0 NOK	67,06 %	0 NOK	2 680 NOK	2 680 NOK	100,00 %
2019	Trana Vest	06-27	Flatfisk, annen bunnfisk og dypvannsfisk	28 m og over	0 NOK	89,43 %	0 NOK	94 423 NOK	94 423 NOK	100,00 %
2019	Trana Vest	06-27	Pelagisk fisk	28 m og over	114 390 NOK	35,41 %	40 508 NOK	5 169 234 NOK	5 209 742 NOK	99,15 %
2019	Trana Vest	06-27	Torsk og torskeartet fisk	28 m og over	0 NOK	71,99 %	0 NOK	568 134 NOK	568 134 NOK	99,87 %
Total					**11 798 851 NOK**	**711,81 %**	**677 100 NOK**	**21 359 974 NOK**	**22 037 074 NOK**	**1429,43 %**

Table A0.6: Valuation: Trænafjorden Nord

Year	Wind park	Catch area	Species	Lenght Group	Total value catch area no tracing	% og value inside wind park	Estimated value wind park no tracing	Value of wind park tracing only	Total value of wind park	AIS/VMS
2017	Tranafjorden Nord	06-31	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	0 NOK	2,81 %	0 NOK	13 NOK	13 NOK	100,00 %
2017	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	17 519 NOK	9,36 %	1 639 NOK	56 160 NOK	57 799 NOK	97,78 %
2017	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	11-14,99 m	151 027 NOK	8,55 %	12 907 NOK	397 101 NOK	410 008 NOK	97,48 %
2017	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 302 068 NOK	12,04 %	156 726 NOK	148 007 NOK	304 733 NOK	47,27 %
2017	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	Under 11 m	3 115 386 NOK	13,85 %	431 405 NOK	189 232 NOK	620 638 NOK	30,02 %
2018	Tranafjorden Nord	06-31	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	0 NOK	21,25 %	0 NOK	36 NOK	36 NOK	100,00 %
2018	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	0 NOK	6,91 %	0 NOK	40 898 NOK	40 898 NOK	100,00 %
2018	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	11-14,99 m	37 777 NOK	11,64 %	4 397 NOK	761 883 NOK	766 279 NOK	98,71 %
2018	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 000 247 NOK	19,67 %	196 745 NOK	233 531 NOK	430 276 NOK	55,03 %
2018	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	Under 11 m	3 004 857 NOK	23,30 %	700 008 NOK	433 019 NOK	1 133 027 NOK	37,64 %
2019	Tranafjorden Nord	06-31	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	102 NOK	11,47 %	12 NOK	123 NOK	135 NOK	85,99 %
2019	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	152 661 NOK	9,81 %	14 983 NOK	90 593 NOK	105 576 NOK	90,81 %
2019	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	11-14,99 m	311 623 NOK	11,86 %	36 945 NOK	602 113 NOK	639 058 NOK	94,03 %
2019	Tranafjorden Nord	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 564 833 NOK	10,20 %	159 594 NOK	92 350 NOK	251 944 NOK	38,70 %
2019	Tranafjorden Nord	06-31	Torsk og torskeartet fisk	Under 11 m	3 513 896 NOK	9,17 %	322 311 NOK	131 716 NOK	454 027 NOK	28,28 %
Total					**14 171 996 NOK**	**181,89 %**	**2 037 673 NOK**	**3 176 774 NOK**	**5 214 447 NOK**	**1101,74 %**

Table A0.7: Valuation: Trænafjorden Sør

Year	Wind park	Catch area	Species	Lenght Group	Total value catch area no tracing	% og value inside wind park	Estimated value wind park no tracing	Value of wind park tracing only	Total value of wind park	AIS/VMS
2017	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	17 519 NOK	2,98 %	521 NOK	17 866 NOK	18 388 NOK	97,78 %
2017	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	11-14,99 m	151 027 NOK	3,58 %	5 408 NOK	166 375 NOK	171 783 NOK	97,48 %
2017	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	0 NOK	1,94 %	0 NOK	72 NOK	72 NOK	100,00 %
2017	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	44 073 NOK	7,66 %	3 376 NOK	146 690 NOK	150 067 NOK	98,76 %
2017	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	11-14,99 m	28 382 NOK	31,76 %	9 014 NOK	1 676 184 NOK	1 685 197 NOK	99,51 %
2017	Tranafjorden Sør	06-33	Pelagisk fisk	21-27,99 m	0 NOK	100,00 %	0 NOK	312 647 NOK	312 647 NOK	100,00 %
2017	Tranafjorden Sør	06-33	Pelagisk fisk	28 m og over	0 NOK	10,34 %	0 NOK	33 889 NOK	33 889 NOK	100,00 %
2017	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 302 068 NOK	0,23 %	2 970 NOK	2 805 NOK	5 775 NOK	47,27 %
2017	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	Under 11 m	3 115 386 NOK	0,36 %	11 100 NOK	4 869 NOK	15 969 NOK	30,02 %
2017	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	Under 11 m	231 NOK	0,58 %	1 NOK	2 NOK	4 NOK	62,34 %
2017	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	940 888 NOK	4,85 %	45 662 NOK	40 600 NOK	86 262 NOK	50,02 %
2017	Tranafjorden Sør	06-33	Pelagisk fisk	Under 11 m	0 NOK	0,86 %	0 NOK	593 NOK	593 NOK	100,00 %
2017	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	Under 11 m	1 738 496 NOK	2,69 %	46 726 NOK	43 534 NOK	90 260 NOK	51,15 %
2018	Tranafjorden Sør	06-31	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	0 NOK	10,45 %	0 NOK	17 NOK	17 NOK	100,00 %
2018	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	0 NOK	4,50 %	0 NOK	26 652 NOK	26 652 NOK	100,00 %
2018	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	11-14,99 m	37 777 NOK	1,87 %	706 NOK	122 281 NOK	122 987 NOK	98,71 %
2018	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	1 654 NOK	6,29 %	104 NOK	115 NOK	219 NOK	81,94 %
2018	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	115 661 NOK	9,01 %	10 420 NOK	132 416 NOK	142 835 NOK	94,98 %
2018	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	11-14,99 m	46 524 NOK	21,12 %	9 825 NOK	911 156 NOK	920 981 NOK	98,85 %
2018	Tranafjorden Sør	06-31	Pelagisk fisk	21-27,99 m	0 NOK	25,34 %	0 NOK	178 107 NOK	178 107 NOK	100,00 %
2018	Tranafjorden Sør	06-33	Pelagisk fisk	21-27,99 m	0 NOK	100,00 %	0 NOK	178 107 NOK	178 107 NOK	100,00 %
2018	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 000 247 NOK	0,02 %	222 NOK	263 NOK	485 NOK	55,03 %
2018	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	Under 11 m	3 004 857 NOK	0,58 %	17 487 NOK	10 817 NOK	28 304 NOK	37,64 %
2018	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	Under 11 m	145 NOK	2,05 %	3 NOK	18 NOK	21 NOK	78,68 %
2018	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 013 815 NOK	3,82 %	38 692 NOK	29 277 NOK	67 969 NOK	46,31 %
2018	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	Under 11 m	3 383 477 NOK	5,83 %	197 306 NOK	155 046 NOK	352 352 NOK	44,31 %
2019	Tranafjorden Sør	06-31	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	102 NOK	1,88 %	2 NOK	20 NOK	22 NOK	85,99 %
2019	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	152 661 NOK	2,64 %	4 037 NOK	24 406 NOK	28 443 NOK	90,81 %
2019	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	11-14,99 m	311 623 NOK	2,06 %	6 406 NOK	104 403 NOK	110 809 NOK	94,03 %
2019	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	11-14,99 m	1 276 NOK	4,52 %	58 NOK	73 NOK	131 NOK	87,42 %
2019	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	11-14,99 m	308 332 NOK	7,25 %	22 353 NOK	114 996 NOK	137 349 NOK	87,72 %
2019	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	11-14,99 m	533 227 NOK	21,91 %	116 809 NOK	963 777 NOK	1 080 586 NOK	93,31 %
2019	Tranafjorden Sør	06-33	Pelagisk fisk	28 m og over	0 NOK	100,00 %	0 NOK	21 750 NOK	21 750 NOK	100,00 %
2019	Tranafjorden Sør	06-31	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	1 564 833 NOK	0,06 %	907 NOK	525 NOK	1 432 NOK	38,70 %
2019	Tranafjorden Sør	06-31	Torsk og torskeartet fisk	Under 11 m	3 513 896 NOK	0,16 %	5 749 NOK	2 350 NOK	8 099 NOK	28,28 %
2019	Tranafjorden Sør	06-33	Bruskfisk (haifisk, skater, rokker og havmus)	Under 11 m	155 NOK	1,42 %	2 NOK	31 NOK	33 NOK	91,76 %
2019	Tranafjorden Sør	06-33	Flatfisk, annen bunnfisk og dypvannsfisk	Under 11 m	755 520 NOK	6,97 %	52 662 NOK	86 980 NOK	139 642 NOK	59,74 %
2019	Tranafjorden Sør	06-33	Torsk og torskeartet fisk	Under 11 m	3 187 968 NOK	1,20 %	38 282 NOK	42 471 NOK	80 752 NOK	54,35 %
Total					**26 271 820 NOK**	**508,78 %**	**646 809 NOK**	**5 552 183 NOK**	**6 198 991 NOK**	**2982,89 %**

A0.5 Calculation of trips and detours

Table A0.8: Respective column names to codes in table A0.9

Column code	Column name
1	Year
2	Wind park name
3	Lenght Group
4	Gear
5	Avg. crew
6	Count of trip in wind park with coordinates
7	Count of trip in catch area with coordinates
8	Sample percentage: (col 6/col 7)
9	Count of trip in catch area no coordinates
10	Estimated number of trips in wind park no coordinates
11	Hourly detour

Table A0.9: Calculation of how we estimate the number of trips in wind park areas without coordinates based on the sample that has coordinates

1	2	3	4	5	6	7	8	9	10	11
2017	Træna Vest	28 m and over	All	14.90	0.00	46.00	0,00 %	0	0,00	0.00
2017	Trænafjorden Sør	Under 11 m	All but yarns and pots	1.50	9.00	261.00	3,45 %	144	4,97	9.63
2017	Trænafjorden Sør	Under 11 m	Yarn and pots	1.50	2.00	498.00	0,40 %	547	2,20	3.55
2017	Trænafjorden Sør	11-14,99 m	Yarn and pots	4.60	36.00	394.00	9,14 %	3	0,27	1.36
2017	Trænafjorden Sør	11-14,99 m	All but yarns and pots	4.60	49.00	208.00	23,56 %	14	3,30	19.62
2017	Trænafjoren Nord	Under 11 m	All but yarns and pots	1.50	22.00	198.00	11,11 %	449	49,89	72.59
2017	Trænafjoren Nord	Under 11 m	Yarns and pots	1.50	27.00	532.00	5,08 %	619	31,42	33.01
2017	Trænafjoren Nord	11-14,99 m	All but yarns and pots	4.60	5.00	199.00	2,51 %	1	0,03	0.11
2017	Trænafjoren Nord	11-14,99 m	Yarns and pots	4.60	23.00	332.00	6,93 %	14	0,97	3.13
2018	Træna Vest	28 m and over	All	14.90	0.00	71.00	0,00 %	0.00	0,00	0.00
2018	Trænafjorden Sør	Under 11 m	All but yarns and pots	1.50	7.00	269.00	2,60 %	278	7,23	14.03
2018	Trænafjorden Sør	Under 11 m	Yarn and pots	1.50	7.00	652.00	1,07 %	915	9,82	15.88
2018	Trænafjorden Sør	11-14,99 m	All but yarns and pots	4.60	44.00	216.00	20,37 %	24	4,89	29.09
2018	Trænafjorden Sør	11-14,99 m	Yarn and pots	4.60	4.00	389.00	1,03 %	122	1,25	6.22
2018	Trænafjoren Nord	Under 11 m	All but yarns and pots	1.50	17.00	181.00	9,39 %	272	25,55	37.17
2018	Trænafjoren Nord	Under 11 m	Yarns and pots	1.50	38.00	661.00	5,75 %	692	39,78	41.80
2018	Trænafjoren Nord	11-14,99 m	All but yarns and pots	4.60	3.00	256.00	1,17 %	1	0,01	0.05
2018	Trænafjoren Nord	11-14,99 m	Yarns and pots	4.60	22.00	362.00	6,08 %	5	0,30	0.98
2019	Træna Vest	28 m and over	All	14.90	0.00	76.00	0,00 %	0.00	0,00	0.00
2019	Trænafjorden Sør	Under 11 m	All but yarns and pots	1.50	6.00	250.00	2,40 %	197	4,73	9.17
2019	Trænafjorden Sør	Under 11 m	Yarn and pots	1.50	5.00	637.00	0,78 %	811	6,37	10.29
2019	Trænafjorden Sør	11-14,99 m	All but yarns and pots	4.60	30.00	196.00	15,31 %	21	3,21	19.12
2019	Trænafjorden Sør	11-14,99 m	Yarn and pots	4.60	15.00	382.00	3,93 %	128	5,03	24.92
2019	Trænafjoren Nord	Under 11 m	All but yarns and pots	1.50	13.00	160.00	8,13 %	232	18,85	27.43
2019	Trænafjoren Nord	Under 11 m	Yarns and pots	1.50	10.00	559.00	1,79 %	623	11,14	11.71
2019	Trænafjoren Nord	11-14,99 m	All but yarns and pots	4.60	3.00	223.00	1,35 %	11	0,15	0.66
2019	Trænafjoren Nord	11-14,99 m	Yarns and pots	4.60	18.00	256.00	7,03 %	39	2,74	8.84

A0.6 Detour by length group

Table A0.10: Detailed distribution of detour by length

Wind park	Træna Vest			Trænafjorden Nord			Trænafjorden Sør			**Total**		
Reason for detour	Detour NM	Detour in hours	Fuel cost	Detour NM	Detour in hours	Fuel cost	Detour NM	Detour in hours	Fuel cost	**Detour NM**	**Detour in hours**	**Fuel cost**
⊟ **Detour approach 1**	**1449**	**2135**	**12 556 205 NOK**	**432**	**139**	**109 179 NOK**	**1787**	**694**	**1 008 676 NOK**	**3668**	**2968**	**13 674 061 NOK**
11-14,99 m	8	4	4 324 NOK	211	97	65 558 NOK	957	439	264 666 NOK	**1176**	**540**	**334 548 NOK**
15-20,99 m	3	2	2 313 NOK				12	9	16 973 NOK	**15**	**11**	**19 285 NOK**
21-27,99 m	29	36	82 928 NOK	3	3	6 911 NOK	13	16	31 330 NOK	**44**	**56**	**121 169 NOK**
28 m og over	1407	2092	12 466 524 NOK	5	7	28 293 NOK	82	121	654 968 NOK	**1494**	**2221**	**13 149 786 NOK**
Under 11 m	2	0	116 NOK	213	32	8 417 NOK	724	108	40 740 NOK	**939**	**141**	**49 272 NOK**
⊟ **Detour approach 2: With coordinates**				**1581**	**407**	**13 132 NOK**	**2624**	**1070**	**63 211 NOK**	**4205**	**1476**	**76 343 NOK**
11-14,99 m				549	252	10 349 NOK	2188	1004	61 000 NOK	**2737**	**1257**	**71 349 NOK**
Under 11 m				1032	154	2 784 NOK	436	65	2 211 NOK	**1468**	**220**	**4 994 NOK**
⊟ **Detour approach 2: Without coordinates**	**0**	**0**	**0 NOK**	**1524**	**237**	**81 273 NOK**	**636**	**163**	**92 982 NOK**	**2161**	**400**	**174 255 NOK**
11-14,99 m				30	14	10 024 NOK	219	100	73 057 NOK	**249**	**114**	**83 081 NOK**
28 m og over	0	0	0 NOK							**0**	**0**	**0 NOK**
Under 11 m				1494	224	71 249 NOK	418	63	19 925 NOK	**1912**	**286**	**91 174 NOK**
Total	**1449**	**2135**	**12 556 205 NOK**	**3537**	**784**	**203 584 NOK**	**5048**	**1927**	**1 164 869 NOK**	**10034**	**4845**	**13 924 659 NOK**

A0.7 Input variables

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Engine	Density of fuel	Consumption in g/hp/hour
2-stroke petrol	0.72	400-500
2-stroke petrol (improved)	0.72	300-400
4-stroke petrol	0.72	220-270
Diesel	0.84	170-200
Diesel (turbo-charged)	0.84	155-180

—*Consumption of fuel by an engine during a given period of time*
C = 0.75 × P(max) × (S/d) × † × 0.001

where
0.75 is an average coefficient; free running it is between 0.7 and 0.8 and when fishing 0.5 to 0.8

C	= consumption (in litres)
P(max)	= maximum power at engine in HP
S	= specific consumption of due in grams/HP/hour
D	= density of fuel
†	= time of use of engine in hours

Figure A0.18: Explanation of algorithm computing fuel consumption pr hour. Source: 2020