Best Available Techniques

- Guideline proposal for Det Norske Veritas

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Best Available Techniques – Guideline proposal for Det Norske Veritas

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Nyckelord: *Best Available Techniques, BAT, Bästa tillgängliga teknik, metodik, miljö, olje- och gas, IPPC*

Key words: *Best Available Techniques, BAT, methodology, environment, oil and gas, IPPC*

Sammanfattning

Detta examensarbete har utförts på uppdrag av Det Norske Veritas (DNV) vid institutionen för Energivetenskaper på Lunds Tekniska Högskola. Syftet var att för DNV:s räkning utveckla en strukturerad och enhetlig metodik för Best Available Techniques (BAT)-värderingar av olje- och gasinstallationer. BAT är ett begrepp som definieras i EU-direktivet Integrated Pollution Prevention and Control (IPPC) (2008/1/EC). Enligt IPPC-direktivet är BAT de tekniker som lever upp till utsläppskrav och minskar den totala miljöpåverkan samtidigt som de är ekonomiskt och tekniskt tillgängliga. Examensarbetet har utförts genom litteraturstudier av framförallt IPPC-direktivet och tillhörande stöddokument samt redan utförda BAT-rapporter. För att bygga upp metodiken utfördes också två fiktiva BAT-värderingar. Metodiken är skriven på engelska. I den framtagna metodiken tolkas BAT framförallt som ett verktyg för att jämföra miljöpåverkan från olika tekniker. Fokus i utvecklingen av metodiken har legat på driften av olje- och gasplattformar. Metodiken baseras huvudsakligen på ett EU-referensdokument (IPPC Reference Document on Economics and Cross-Media Effects) och är uppdelad i sju moduler. Mycket inspiration till innehållet i dessa moduler har hämtats från strukturen på livscykelanalyser som beskrivs i ISO 14040. Under arbetets gång har vi kunnat konstatera att många bedömningar i BAT-processen är kvalitativa och måste göras från fall till fall. En stor svårighet i BAT-värderingar ligger i att väga olika typer miljöpåverkan mot varandra. BAT-begreppets vaga definition gör att dess effektivitet som miljöverktyg avgörs av inställningen hos de som utför värderingen och tar beslut utifrån den.

Nyckelord: *Best Available Techniques, BAT, Bästa tillgängliga teknik, metodik, miljö, olje- och gas, IPPC*

Abstract

This master thesis was commissioned by Det Norske Veritas (DNV) and was conducted at the department of Energy Sciences at the Faculty of Engineering, Lund University. The purpose of the thesis was to develop a structured and uniform methodology for Best Available Techniques (BAT) assessments of oil- and gas installations. BAT is defined in the EU directive on Integrated Pollution Prevention and Control (IPPC) (2008/1/EC). The thesis was conducted through studies of this directive and its associated reference documents. In addition, existing BAT reports were studied. In order to develop the methodology two fictitious BAT assessments were conducted. In the proposed guideline BAT is interpreted chiefly as a tool to compare the environmental performance of different techniques. The methodology has been based mainly on an EU reference document (IPPC Reference Document on Economics and Cross-Media Effects) and is divided into seven modules. These modules have been inspired largely by the structure of life cycle analysis as described in the ISO 14040 standard. While writing the thesis we have concluded that many of the evaluations done in a BAT assessment are qualitative and must be performed on a case-by-case basis. Moreover, it is inherently difficult to compare different environmental impacts. The definition of BAT is relatively vague. As a result, its efficiency as an environmental tool is determined by the attitude of those who conduct them and of those who base their decisions upon them.

Key words: *Best Available Techniques, BAT, methodology, environment, oil and gas, IPPC*

Förord

Denna rapport sammanställer vårt examensarbete som utförts under cirka sex månaders tid med start 3 mars 2010. Arbetet har huvudsakligen genomförts på och för Det Norske Veritas (DNV) i Oslo och med kontinuerlig kontakt med Institutionen för Energivetenskaper på Lunds Tekniska Högskola (LTH). Examensarbetet är avslutningen på våra studier till Civilingenjörer i Ekosystemteknik/Environmental Engineering vid Lunds Universitet.

Uppgiften att bygga upp en metodik för att göra värderingar om vad som är Best Available Techniques (BAT) kommer ursprungligen från DNV och vi vill först tacka DNV och avdelningen *Environmental Measures & Technology* för en intressant, mångfaciterad men även utmanande uppgift. Mer specifikt vill vi tacka vår handledare Siv Haukebø för all handledning och tid som du ägnat oss. Din kunskap om olje- och gasbranschen var central i projektets början och de löpande tips vi fick under arbetets gång har varit värdefulla. Vi vill även tacka Axel Edward Kelley för att du delat med dig av din långa erfarenhet av miljöarbete inom branschen och gett din syn på begreppet BAT. Slutligen tackar vi även Ole Øystein Aspholm för möjligheten att skriva exjobbet för DNV, ett varmt välkomnande och god uppmuntran under arbetets gång.

På Institutionen för Energivetenskaper vid Lunds Tekniska Högskola vill vi först och främst tacka Prof.em. Lennart Thörnqvist som varit vår handledare. Du har engagerat dig mer än vad man kan förvänta sig, inte minst genom att resa upp till Oslo för handledarmöte. Din gedigna erfarenhet av att handleda examensarbeten har bidragit mycket till att förbättra den guideline som är produkten av examensarbetet och som vi hoppas ska bli värdefull i DNV:s framtida miljöarbete. Vi tackar även Prof. Svend Fredriksen, vår examinator, samt Gunvi Andersson, sekreterare på institutionen för er tid.

Innehållsförteckning

1 Inledning

Intresset för miljöförbättrande åtgärder växte sig starkt på 1960-talet då bland annat Rachel Carsons bok ”Tyst vår” publicerades. Carson beskriver i denna bok konsekvenserna av kemikalieanvändning och genast var en livlig debatt inledd. Denna debatt växte sig större under 1970-talet i och med energikriserna och på 1980-talet då Tjernobylkatastrofen inträffade. Miljöåtgärder har samtidigt gått från att fokusera på lokala till globala problem. Fram till 1990-talet koncentrerades mycket av miljöarbetet på punktutsläpp från olika källor. I den så kallade Brundtlandrapporten beskrevs för första gången ”hållbar utveckling” och denna definierades senare vid FN:s konferens om miljö och utveckling i Rio de Janeiro 1992 (Rydh et al. 1997). Därmed var grunden för mycket miljöarbete och många miljöverktyg lagd. Under 1980- och 1990-talen utvecklades många sådana verktyg, bl.a. livscykelanalyser (LCA), miljöstyrning, miljökonsekvensbeskrivningar (MKB) och Best Available Techniques (BAT) (sv. Bästa Tillgängliga Teknik).

1.1 Best Available Techniques

BAT som begrepp har sitt ursprung i EU:s ramverk Best Available Technology Not Entailing Excessive Costs (BATNEEC) som introducerades 1984 inom Air Framework Directive (AFD) (84/360/EEC). Ramverket syftade till att begränsa utsläppen till luft från storskaliga industriella anläggningar. 1996 ersattes BATNEEC-begreppet av Best Available Techniques (BAT) som en konsekvens av att tyskt regelverk med betoning på teknisk tillgänglighet och kvalificering mötte den brittiska kravtraditionen som fokuserade på ekonomisk genomförbarhet och individuella bedömningar. Dessa två synsätt slogs samman i Integrated Pollution Prevention and Control (IPPC) –direktivet (96/61/EC) som uppdaterades 2008 (2008/1/EC) (Sorrell 2002; EU 2010).

Syftet med IPPC-direktivet är att enhetligt förebygga utsläpp och förorening från en rad källor och i artikel 12 i samma direktiv definieras BAT som begrepp:

> ’best available techniques’ means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole… (2008/1/EC)

BAT ska således innebära de mest effektiva och avancerade teknikerna, samt hur dessa används. Samtidigt ska hänsyn tas till deras praktiska lämplighet. Detta ska huvudsakligen göras i syfte att leva upp till utsläppskrav men även syfta till att i allmänhet minska utsläpp och den totala miljöpåverkan. I artikel 12 definieras vidare de ingående termerna i BAT:

> ’techniques’ shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
>
> ‘available techniques’ means those developed on a scale which allow implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the

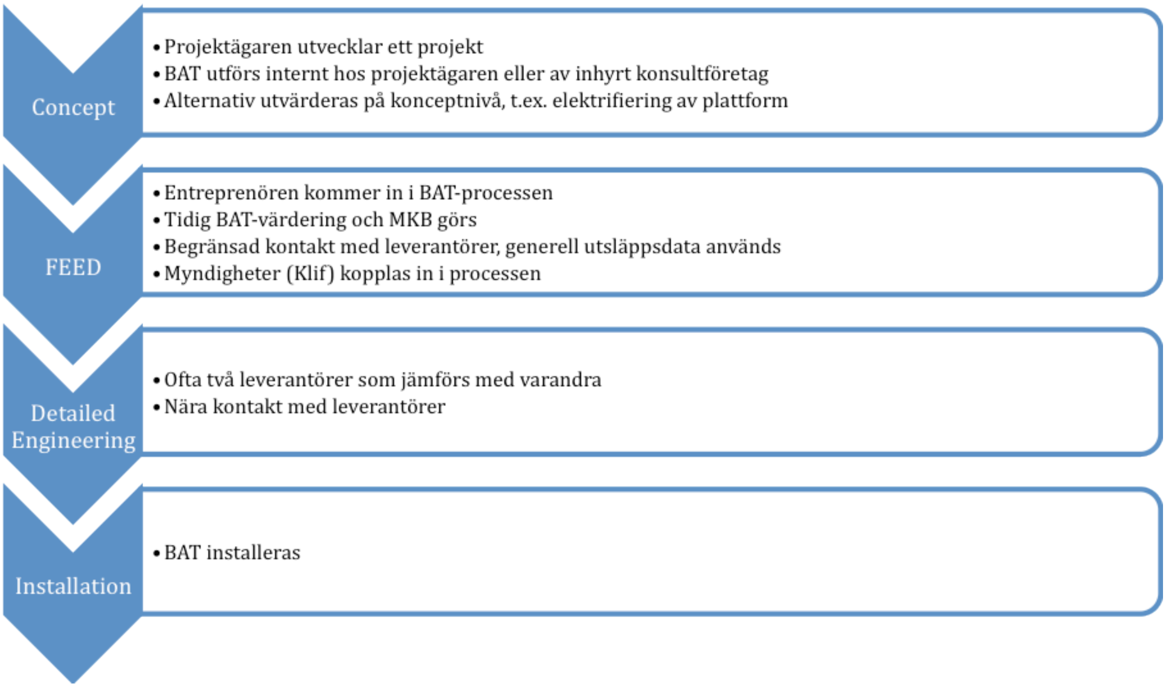
> Member State in question, as long as they are reasonably accessible to the operator;
>
> ‘best’ means most effective in achieving a high general level of protection of the environment as a whole (2008/1/EC).

Med tekniker menas alltså själva tekniken men även hur den designas, byggs, underhålls, sköts och monteras ned. Definitionen av ”tillgänglig” är mer komplex. Denna term ska innefatta tekniker som är tillräckligt utvecklade för att produceras i stor skala och implementeras i den aktuella sektorn. Detta ska kunna göras på ett såväl ekonomiskt som hållbart sätt och dessutom genom att väga kostnader mot fördelar med den studerade tekniken. Teknikerna ska även vara rimligt tillgängliga för anskaffning, men behöver inte nödvändigtvis tillverkas i det aktuella landet. I IPPC-direktivet specificeras även de aspekter som ska tas hänsyn till för att en teknik ska klassas som BAT. I direktivet poängteras att detta görs samtidigt som man beaktar kostnader och fördelarna med teknikerna samt väger in försiktighetsprincipen. I Tabell 1 nedan visas i vänstra kolumnen formuleringarna i IPPC-direktivet samt, i den högra, våra tolkningar av varje kategori då de appliceras i den efterföljande guidelinen.

Tabell 1 IPPC-direktivets ANNEX IV: 12 aspekter att beakta i BAT-värderingar och vår tolkning av dessa (2008/1/EC).

The use of low waste technology	The amount and type of waste generated by a specific technique
The use of less hazardous substances	The amount and type of chemicals used by a specific technique
The furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate	The recycling percentage of used and generated substances
Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale	The number of times a technique has been installed/implemented offshore under similar conditions
Technological advances and changes in scientific knowledge and understanding	The technical maturity of new techniques
The nature, effects and volume of the emissions concerned	The amount of emissions emitted and their resulting environmental impact
The commissioning dates for new or existing installations	The installation date and operation time of the technique
The length of time needed to introduce the best available technique	The estimated time before the technique can be proved available
The consumption and nature of raw materials (including water) used in the process and energy efficiency	The consumption and nature of raw materials (including water) used in the technique and energy efficiency
The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it	The relevance of different stressors and EICs in relation to the total environmental impact caused by the technique
The need to prevent accidents and to minimize the consequences for the environment	The potential environmental risk and risk barriers associated with the specific technique
The information published by the Commission pursuant to Article 17(2), second subparagraph, or by international organisations	The compliance with existing regulation and laws and third party research

Praktiskt används BAT dels som begrepp för att benämna en teknik och dels för att hänvisa till det arbetssätt som används då man bedömer vilken teknik som är BAT. Sådana bedömningar kommer i det här dokumentet att refereras till som BAT-värderingar. Dessa utförs i enlighet med IPPC-direktivet i hela EU då nya projekt och installationer planeras. IPPC-direktivet har även implementerats i Norge i bl.a. det s.k. NORSOK S-003 som reglerar miljöarbetet inom oljesektorn i Norge (SN 2005). Inom den norska oljesektorn kan BAT-värderingar göras på olika nivåer – i olika faser av ett projekts utveckling – och av olika intressenter. Detta visas i Figur 1 nedan.



Concept
- Projektägaren utvecklar ett projekt
- BAT utförs internt hos projektägaren eller av inhyrt konsultföretag
- Alternativ utvärderas på konceptnivå, t.ex. elektrifiering av plattform

FEED
- Entreprenören kommer in i BAT-processen
- Tidig BAT-värdering och MKB görs
- Begränsad kontakt med leverantörer, generell utsläppsdata används
- Myndigheter (Klif) kopplas in i processen

Detailed Engineering
- Ofta två leverantörer som jämförs med varandra
- Nära kontakt med leverantörer

Installation
- BAT installeras

Figur 1 De olika nivåer som BAT-värderingar kan utföras på (Kirkeng 2010).

BAT bör alltså vara ett koncept som genomsyrar hela utvecklingen av projektet och involvera samtliga intressenter. Att BAT-värderingar av valda tekniker utförts ska framgå av miljökonsekvensbeskrivningen (MKB) som granskas av myndigheterna. Att sammanställa MKB:n faller under Projektägarens ansvar och de kräver ofta av Entreprenören att en BAT-värdering av ingående komponenter gjorts. I konceptfasen kan även BAT-värderingar göras inom Projektägarens organisation (Kirkeng 2010). I Norge görs denna granskning av Klima- og forurensningsdirektoratet (Klif). Enligt Klif blir de dock ofta inte inkopplade förrän i förstudien (FEED), då många viktiga konceptval redan gjorts (Sandgrind 2010). De viktigaste intressenterna i BAT-processen är (Kirkeng 2010):

- Projektägaren, t.ex. Statoil
  - Utvecklar, opererar och äger oljeplattformen
- Entreprenören, t.ex. Aker Solutions
  - Sätter ihop helhetslösningen för plattformen, dvs. plattformslösning tillsammans med gasturbiner, brunnskontruktioner, pumpar etc.
- Leverantören, t.ex. Siemens
  - Levererar de enskilda komponenterna till Entreprenören, t.ex. gasturbiner för energiförsörjning.
- Myndigheter, t.ex. Klif

    - Granskar miljökonsekvensbeskrivningen och bedömer bl.a. om BAT-värdering gjorts på ett riktigt sätt.
- Konsultföretag, t.ex. DNV
    - Kan hyras in av Projektägare och/eller Konstruktör för att utföra BAT-värdering av hela koncept eller enskilda komponenter.

1.2 Bakgrund till examensarbetet

Det Norske Veritas (DNV) är från början ett klassificeringsföretag inom skeppsindustrin som grundades 1864. Idag arbetar de även med teknikkvalifikation och renodlade konsulttjänster inom olika områden. Oljeindustrin har idag ersatt skeppsnäringen som största kund. DNV drivs som en stiftelse och litar i sin klassificerings- och kvalifikationsroll mycket till sin framtoning som en trovärdig och oberoende part.

DNV har märkt en sakta ökande efterfråga för BAT-värderingar från sina kunder (Projektägare och Entreprenör). Idag görs dock dessa, såväl utanför som inom DNV, på olika sätt och med olika prioriteringsområden. DNV önskar därför en metodik som definierar hur de på ett strukturerat vis ska utföra BAT-värderingar.

1.3 Frågeställning

Mot denna bakgrund utvecklade vi följande frågeställningar för vårt examensarbete:

- Vad innebär begreppet Best Available Techniques som definieras i IPPC-direktivet och hur ska detta tillämpas praktiskt?
- Hur utvecklar man en metodik enligt styrande krav och regler som DNV kan tillämpa för att praktiskt, strukturerat och enhetligt genomföra BAT-värderingar för drift av olje- och gasplattformar?

1.4 Syfte

Syftet med examensarbetet är att utarbeta en praktisk metodik som DNV kan använda för att på ett enhetligt, trovärdigt och effektivt sätt genomföra BAT värderingar för driften av olje- och gasplattformar.

2 Metod

Examensarbetet utfördes till största del på DNV:s kontor i Høvik utanför Oslo. Handledare för examensarbetet har, från Lunds Tekniska Högskola, varit Prof.em. Lennart Thörnqvist och, från DNV, M.Sc. Siv Haukebø.

DNV önskade en metodik (guideline) för BAT-värderingar som skulle appliceras på olje- och gasplattformar. Eftersom våra kunskaper inom oljebranschen var begränsade innan examensarbetet inledde vi detta med att sätta oss in i grundläggande funktioner på en olje- och gasplattform. När vi kom till DNV i Oslo satte vi oss in i IPPC-direktivet, de referensdokument som hör till detta samt studerade vissa utförda BAT-värderingar. I de flesta fall fann vi dessa otillräckliga i förhållande till IPPC-direktivet och referensdokumentet IPPC Reference Document on Economics and Cross-Media Effects (ECM), vilket beskriver en metodik för BAT-värderingar. ECM-dokumentet inspirerade arbetet med att ta fram en metodik för DNV på många sätt, men i många avseenden fann vi också ett stort behov av att utveckla och problematisera denna för att praktiskt kunna använda sig av metodiken.

I inledningen av examensarbetet fann vi det svårt att komma igång med skrivandet av BAT-metodiken. Därför började vi tidigt med en exempelvärdering (bilge water treatment), där vi tillämpade de riktlinjer kring BAT som vi hade att tillgå. Samtidigt byggde vi upp metodiken kring erfarenheter från BAT-värderingen. Denna värdering behandlade ett litet delsystem på en oljeplattform och skulle kunna lämpa sig i detaljfasen av ett utvecklingsprojekt. När exemplet var färdigt hade vi ett mycket grovt förslag på en metodik.

För att ytterligare utveckla metodiken utförde vi ännu en BAT-värdering som vi – för att få en så heltäckande guideline som möjligt – önskade skulle skilja sig avsevärt från det tidigare exemplet. Av dessa anledningar samt för att dra nytta av vår akademiska bakgrund beslutade vi därför att utvärdera energiproduktion för en plattform på konceptbasis. Parallellt med arbetet med detta exempel utvecklades metodiken betydligt.

Examensarbetet har utförts av två studenter med liknande akademisk bakgrund. Detta har varit mycket hjälpsamt då vi funnit BAT-begreppet som relativt vagt definierat och BAT-arbetsättet som ostrukturerat. Tillsammans har vi dock kunnat diskutera oss fram till gemensamma definitioner och strukturer. Självklart har feedback och diskussioner med våra handledare också hjälpt oss mycket.

DNV är ett internationellt företag och för att den framtagna metodiken ska kunna användas av samtliga anställda skrevs den på engelska. Metodiken som presenteras nedan är dessutom tänkt att kunna användas helt självständigt av DNV:s anställda, dvs. utan dessa omslutande kapitel. Därför förekommer en del upprepningar i examensarbetet som helhet.

3 Intressenter om BAT

För att få en mer nyanserad bild av vad begreppet BAT innebär och hur det tillämpas i olje- och gasindustrin har olika typiska intressenter i BAT-processen intervjuats. Valet av intervjuobjekt har gjorts för att få en så heltäckande bild av BAT-processen och de olika parterna som möjligt inom den givna tidsramen för examensarbetet. Intervjuerna har sedan använts som informationskälla för att utveckla guidelinen, samt för att kontrollera att dess rekommendationer stämmer överens med hur begreppet tolkas och används i industrin. Fyra olika intervjuer har gjorts med följande typiska intressenter i BAT-sammanhang; ett oljebolag (projektägare) representerat av Statoil, en ingenjörsfirma representerat av Aker Solutions, den kontrollerande myndigheten representerat av Klima og forurensningsdirektoratet (Klif), samt ytterligare en statlig myndighet ansvarig för forskningsstöd för teknikutveckling representerat av Forskningsrådet. Frågorna som ställdes under de fyra intervjuerna var i stort sett samma och presenteras nedan.

1. *Hur tolkar ni begreppet BAT?*
    a. *Termen som helhet?*
    b. *Hur tolkar ni varje ord i begreppet; Best, Available, Techniques?*
    c. *Vilken roll spelar ni i BAT-processen?*

2. *Enligt IPPC-direktivet relaterar ordet Best till vad som är bäst för miljön som helhet.*
    a. *Vilka miljöaspekter ser ni generellt som viktigast när det gäller driften av en olje- och gasplattform för att skydda miljön i stort?*
    b. *Prioriterar ni olika miljöaspekter, och i så fall hur?*

3. *Termen Available berör både ekonomisk och teknisk tillgänglighet och är som vi ser det definierad väldigt vagt i IPPC- direktivet.*
    a. *Hur bedömer ni om en teknik är teknisk tillgänglig?*
    b. *Hur bedömer ni om en teknik är ekonomisk tillgänglig?*
    c. *Om en "cost/benifit-analys" genomförs hur definieras då de miljömässiga fördelarna?*

4. *Vilka system utvärderas vanligtvis i en BAT-värdering för driften av en olje- och gasplattform?*

5. *Vilka är de typiska intressenterna i BAT-processen?*

Nedan följer en sammanställning av svaren på ovanstående ställda frågor för respektive intervju. Exakta svar på alla frågorna visas inte. Istället har vi valt att återge de delar som beskriver hur BAT begreppets olika delar tolkas och används av respektive intressent.

Aker Solutions

Aker Solutions är ett ingenjörsföretag med huvudsaklig verksamhet inom olje- och gasindustrin, processindustri, samt övrig energirelaterad industri. Inom olja och gas arbetar man bland annat med att designa plattformar och delsystem på plattformarna. I ett projekt där Aker Solutions jobbar mot t.ex. Statoil ansvarar man ofta även för att utföra BAT-värderingar på de olika system och koncept som ska användas på plattformen. På kontoret i Oslo är man ca 800 anställda som arbetar med typisk ”engineering” inom olje- och gasindustrin. Den som har mest erfarenhet av miljöarbete och BAT-värderingar är Nina Christine Kirkeng som är utbildad civilingenjör i kemiteknik men som den senaste tiden jobbat framförallt med miljö. Följande är en sammanställning av intervjun som genomfördes 11 juni 2010 på Aker Solutions kontor i Oslo, där Nina ger sin och Aker Solutions syn på begreppet BAT (Kirkeng 2010).

BAT-begreppet är främst en metod för att kontrollera att en teknik (technique) är miljövänlig och samtidigt teknisk tillgänglig. Värderingens omfattning beror mycket på vilket utvecklingssteg som det specifika projektet befinner sig i.

Utifrån de tre ord som utgör begreppet BAT; Best Available Techniques tolkar Nina Best på samma sätt som IPPC; alltså det som är bäst för miljön i stort. Teknisk tillgänglighet tolkar hon som att tekniken som används ska vara beprövad i branschen på motsvarande skala och helst ha en dokumenterad och nästintill felfri driftsstatistik under minst ett år. När det kommer till ekonomisk tillgänglighet finns det ingen enkel metodik för hur detta ska hanteras och bedömas, utan det måste göras från fall till fall.

När det kommer till vilka miljöaspekter som Aker Solution ser som viktigast när man utför BAT-värderingar anger Nina utsläpp till luft, vilket är nära förknippat med energieffektivitet som de viktigaste. För att minska utsläppen till luft måste man uppnå en hög energieffektivitet och på detta sätt kan nyttan per utsläpp maximeras. En viktig del av energieffektivisering är att ta tillvara på den värmen som produceras offshore i bland annat gasturbiner och annan förbränning. Av utsläppen till luft ser man koldioxidutsläppen som viktigaste följt av NO_x, samt utsläpp av nmVOC. CO_2 ges stor tyngd bland annat på grund av att det är svårt att undvika oberoende på vilken energiproduktionsteknik som väljs. Utsläpp till havet kan även visa sig vara en betydande aspekt, framförallt utsläpp av andra kemikalier än olja. Huruvida utsläpp till havet får stor betydelse eller inte beror framförallt på var man befinner sig. I Barentshavet, till exempel, är det nolltolerans på utsläpp till havet, och då måste detta givetvis prioriteras. Detta löser man framförallt genom att reinjicera olja och kemikalier i reservoaren. När man inte injicerar olje- och kemikalieutsläpp kan dessa istället först renas till en nivå som stämmer överens med rådande krav och sedan släppas ut. Det finns en rad teknologier för sådan rening och det blir därmed, i dessa fall, inte lika viktigt att fokusera på som utsläpp till luft. I de fall där det kan finnas en konflikt mellan olika miljöintressen som när ökad rening av utsläpp till havet resulterar i ökad energianvändning och därmed utsläpp till luft finns inget uttalat angreppssätt för att hantera detta. Enligt Nina finns idag inget tillräckligt bra kvantitativt verktyg för att göra denna bedömning utan det måste istället bli en kvalitativ värdering från fall till fall.

För att avgöra om en teknik är ekonomisk tillgänglig använder sig Aker Solutions av kostnadseffektivitetsbedömningar. Med detta menas att man räknar ut vad kostnaden blir per reducerad enhet utsläpp, till exempel NOK/ ton CO_2. Vissa kunder har sedan krav på var kostnadseffektiviteten ska ligga för olika utsläpp för att åtgärder ska anses lönsamma. Oftast är det svårt att göra exakta ekonomiska analyser eftersom leverantörerna av olika utrustningar inte vill publicera kostnader på grund av sekretesskrav. Kostnadseffektivitetsbedömningen blir därför mer översiktligt uppbyggd av nyckeltal förknippat med olika tekniker. Resultatet av denna bedömning blir i regel att de olika teknikerna som värderas presenteras för kunden tillsammans med en rekommendation. Det är sedan upp till kunden att välja vad man är beredd att betala. Ofta är de beredda att betala mer för en teknik med mindre miljöpåverkan om den leder till minskade skatteutgifter eller åtgärder som kan belysas för att förbättra företagets image. På det stora hela är det framförallt direkta kostnadsbesparingar som driver miljöförbättrande åtgärder.

Aker Solution kan utföra BAT-värderingar på de flesta av de system som finns på en plattform, vilka system man värderar beror på i vilket steg av processen man kommer in. Ofta kommer man in efter att Projektägaren, t.ex. Statoil, redan har utvärderat olika koncept och därefter gjort sitt val. I dessa fall kommer Aker Solution in och värderar de olika teknikerna och leverantörerna inom det valda konceptet, till exempel olika typer av gasturbiner etc. Omfattningen på en BAT-värdering kan variera mycket kraftigt, även den beroende på när man kommer in i projektet. Kommer man in tidigt redan i konceptvalsfasen kan det ta åtskilliga år innan värderingen gått igenom faserna, *FEED*, ”*Detailed engineering*” och slutligen installation.

Klima og forurensningsdirektoratet (Klif),
Klif ligger under det norska miljödepartementet och är ansvariga för att verkställa den fastslagna miljöpolitiken. Detta gör man genom att bland annat kontrollera utsläpp, administrera miljöskatter och andra miljöavgifter, samt genom att vara vägvisare inom miljöområdet. Huvudkontoret ligger i Oslo och har ca 325 anställda. För att diskutera BAT på Klif träffade vi Sissel Wiken Sandgrind och Anniken Hoel. Sissel jobbar med miljöfrågor mot on- och offshore oljeindustri, och Anniken med klimat och utsläppsrätter för olje- och gasindustrin. Följande är en sammanställning av intervjun med Anniken och Sissel (Hoel & Sandgrind 2010).

Klif har en viktig roll i BAT-sammanhang som den kontrollerande myndigheten. Kontrollen sker framförallt genom att man uttalar sig i den norska miljökonsekvensbeskrivningsprocessen, där BAT är ett krav för utbyggnader av olje- och gasplattformar på norsk sockel. Det främsta problemet i den här processen är enligt Sissel och Anniken att Klif ofta kommer in för sent då stora teknikkoncept redan är valda. Många gånger har då projektägaren redan tecknat bindande avtal med leverantörer och låst sig i ett teknikval. Istället vill man ha en mer tydlig dialog med projektägaren redan i projektets start.

När det gäller BAT som begrepp använder Klif IPPC-direktivet för att tolka de olika termerna. ”Best” tolkar man som, bäst för miljön som helhet men att åtgärderna samtidigt ska vara kostnadseffektiva för att uppnå de nationella miljömålen på ett så effektivt sätt som möjligt. När det kommer till ”Available” blir det enligt Klif väldigt politiskt att definiera vad som är tillgängligt och inte. Normalt anser man att tillgänglig teknik ska vara beprövad med motsvarande förutsättningar inom EU. ”Proven Technology” kan dock definieras mer strikt än så om man vill. Enligt Klifs tolkning av IPPC så räcker det dock med att en teknik har testats i en annan bransch för att den ska vara tillgänglig och därmed ska värderas för implementering i olje- och gasindustrin. Offshore industrin är dock väldigt konservativa till ny teknik och man vill helst att tekniken redan ska vara använd och körd i över 1000 timmar för att den ska vara tillgänglig. I regel är det svårt att generalisera kring vad som är tillgängligt och inte. Detta måste bedömas individuellt i varje specifikt fall.

Angående vilka miljöaspekter som är viktigast anger Sissel och Anniken först CO_2 och NO_x. CO_2 eftersom Norge ligger långt ifrån de kommande uppsatta nationella målen, och NO_x eftersom det leder både till försurning och övergödning. Vidare ser man även utsläpp av producerat vatten och kemikalier till havet som en viktig aspekt. När det gäller producerat vatten är det framförallt koncentrationen olja i vattnet som släpps ut som är viktig och för kemikalier är det snarare absolut mängd i antal ton.

Att prioritera miljöaspekter är svårt och det finns inget givet sätt att göra detta på utan det måste göras utifrån förutsättningarna från fall till fall. Ett sätt att göra det på är att titta på skillnaderna i avstånd för att uppnå de politiskt uppsatta målen för de olika miljöaspekterna. Är man nära att uppnå ett mål för en aspekt bör den prioriteras lägre än en aspekt där man har långt kvar till målet. Av denna anledning är det nuvarande högt politiskt fokus på CO_2 utsläpp. Historiskt sett har lokala miljöproblem haft högst prioritet, sedan regionala och sist globala.

För att bedöma den ekonomiska tillgängligheten använder Klif sig av ”cost benefit”-analyser och mer specifikt kostnadseffektivitetsanalyser. Den beräknade kostnadseffektiviteten kan sedan relateras till uppskattade nyckeltal på åtgärder som krävs för att uppnå de satta målen. För CO_2-utsläpp finns nyckeltal som visar att om Norge ska klara de åtaganden som man troligtvis blir ålagda genom att ingå i EU:s 2020-mål,och dessutom genomföra dessa åtgärder i Norge, kan kostnadseffektiviteten uppskattas till ca 1000-1500 NOK/ton reducerat CO_2. För NO_x kan en siffra över historiska reduktionsåtgärder uppskattas till ca 50 NOK/ton reducerat NO_x.

Kostnadseffektivitet kan även relateras till den befintliga avgiftsnivån på utsläppet. För CO_2 och olje- och gasindustrin ligger denna siffra idag på ca 375 NOK/ton och består av en reducerad koldioxidskatt, samt kostnader för utsläppsrätter då den norska olje- och gasindustrin sedan 2008 är en del av det europeiska handelssystemet med utsläppsrätter.

På frågan vilka system som ska behandlas inom BAT-processen på en plattform svarar de att alla system och alla aspekter som är relevanta ska BAT-värderas.

Statoil

Statoil är ett norskt energibolag med verksamhet inom framförallt olje- och gasindustrin. Norska staten är majoritetsägare i bolaget och Statoil är en av de största aktörerna på norsk kontinentalsockel. Företaget har även en rad stora projekt utomlands bland annat i Brasilien, Algeriet, och Indonesien. Efter samgåendet med olje- och gasdelen av Norsk Hydro 2007 har man idag ca 29000 anställda och är börsnoterade både i Oslo och New York. Knut Åsnes är ”Leading Advisor Environmental Protection” och ansvarig för att BAT implementeras i de utbyggnader Statoil är delaktiga i. Den 23 juli genomfördes en telefonintervju med Knut om BAT (Åsnes 2010).

Enligt Knut så gäller definitionen som den ges i IPPC-direktivet för implementeringen av BAT i Statoils projekt. Man har dock än så länge ingen uniform struktur, eller internt styrande dokument för hur BAT ska behandlas och värderas. Statoils definition av ”Best” skiljer sig något från tidigare intressenter. Enligt Knut inkluderas hela begreppet BAT i ”Best” vilket menas att både kostnader och tekniska aspekter värderas och att vad som är ”Best” bestäms av den slutgiltiga bedömningen. ”Available” säger Knut att man tolkar snävt i förhållande till IPPC-direktivet eftersom man i praktiken oftast bara använder sig av teknik som blivit använd tidigare av Statoil eller andra operatörer på norsk sockel. I begreppet ”Techniques” inkluderar man inte bara teknologi utan ser det som en vidare term vilket stämmer väl överens med definitionen i IPPC-direktivet.

När det gäller de mest centrala miljöaspekterna anger Knut utsläpp till havet och utsläpp till luft som de viktigaste områdena. Utsläpp till hav utgörs framförallt av producerat vatten varför detta är en viktig fråga. Först måste det utredas om man ska använda sig av injektion eller om vattnet ska renas och sedan släppas ut i havet. Det finns många olika tekniker för att rena vatten varför även detta blir en viktig del i att BAT-värderingar. Utsläpp av borrkemikalier och borrkax är också viktiga aspekter för utsläpp till hav.

Utsläpp till luft är nära kopplat till energiproduktion varför detta är en mycket central aspekt i BAT-värderingar för en plattform. Det är framförallt utsläpp av CO_2 och NO_x som är viktiga att värdera. Av dessa är det CO_2 som är mest betydelsefullt eftersom NO_x-problematiken delvis täcks av NORSOK-standarden som säger att gasturbiner offshore maximalt får släppa ut 25 ppmv NO_x.

Statoil har inget kvantitativt sätt att prioritera olika miljöaspekter. För konflikten mellan utsläpp till hav och utsläpp till luft har man historiskt prioriterat utsläpp till hav eftersom den ökade energianvändningen som en högre reningsgrad av vatten innebär är marginell i förhållande till en plattforms totala energianvändning.

För att bedöma den ekonomiska tillgängligheten för en teknik använde Statoil tidigare nyckeltal för CO_2 och ett verktyg som kallades Environmental Impact Factor (EIF) för utsläpp till hav. EIF är ett verktyg för att göra en helhetsbedömning av miljöskadorna vid utsläpp till hav och man hade då nyckeltal uttryckt i kostnad/ reducerad EIF. Åtgärder som hade en lägre kostnad än det uppsatta nyckeltalet ansågs lönsamma och genomfördes. Användandet av dessa nyckeltal togs dock bort eftersom det var svårt att generalisera kostnader då dessa till stor del berodde på det rådande marknadsläget och framförallt kostnaden för ”engineering” i olika projekt. Idag jobbar man istället med att göra kostnadseffektivitetsbedömningar där man beräknar kostnad/reducerat utsläpp. När man jämför två tekniker kan skillnaden i kostnad tillskrivas skillnaden i miljöprestanda och på så sätt kan en relativ kostnadseffektivitet beräknas. I ett fall där en teknik är billigare och med sämre miljöprestanda kan den ökade kostnaden för den dyrare tekniken hänföras till de reducerade utsläppen och på så sätt uttrycka detta som kostnad/reducerat utsläpp.

När det gäller kostnadseffektivitet för CO_2 är det naturligt att man först jämför med rådande avgifter och skatter för utsläpp i förhållande till vad det kostar att reducera utsläppet. Som nämndes tidigare ligger idag kostnaden för att släppa ut CO_2 i Norge på ca 375 NOK/ton. Åtgärder som resulterar i en högre kostnadseffektivitet än detta är därmed direkt lönsamma och bör genomföras. När kostnadseffektiviteten närmar sig åtskilliga tusentals kronor per reducerat ton CO2 förkastas åtgärden oftast som för dyr. Vanligt förekommande när det gäller åtgärder som har implementeras för att reducera CO_2-utsläpp ligger på runt 600-700 NOK/ton.

Hur och för vilka system BAT-värderingar tillämpas skiljer sig från projekt till projekt men vanligt är att man utvärderar konceptval och olika reningstekniker med BAT-värderingar. Vidare är det även vanligt att energieffektiviseringsåtgärder, värmeåtervinning, variabelt varvtal i pumpar, kallfackling och varmfackling utvärderas i BAT-värderingar. Förutom att implementera BAT så följer Statoil i övrigt rådande lagstiftning i landet där projektet genomförs, samt världsbankens rekommendationer när det gäller miljöprestanda.

Statoil genomför BAT-värderingar själva men lägger även ut det på ingenjörsfirmorna som t.ex. Aker Solutions och Aibel som har närmast kontakt med leverantörerna. Enligt Knut varierar kvaliteten på de BAT-värderingar som man får in utifrån väldigt mycket. Vissa är genomarbetade och heltäckande medan andra har stora brister. Skillnaden i kvalitet kan även variera inom samma företag vilket tyder på att värderingen uppenbarligen beror på vilken kunskap och förståelse för BAT som de personer som utför analysen har.

Forskningsrådet

Forskningsrådet är en organisation som täcker alla sektorer och branscher och delar varje år ut ca 7 miljarder i stöd till forskning inom teknik. De som söker och tilldelas stöd kommer både från det privata näringslivet och akademiska institutioner. För att få forskningsrådets syn på BAT-begreppet i allmänhet och teknologiutveckling och innovation i synnerhet träffade vi Tor Petter Jonson ansvarig för miljöteknikavdelningen (Jonson 2010).

Enligt Tor Petter Jonsson fokuseras det mesta av forskningen inom miljöteknik i Norge idag på utsläpp till vatten och luft. När det gäller tilldelning av medel knutet till hur ”Best” ska definieras anger Tor att det är teknikens prestanda, alltså dess förmåga att uppfylla den tänkta funktionen som är viktigast. Kostnader är även viktiga och bör utvärderas så att teknikerna är inom rimliga ekonomiska ramar. Generellt är det svårt att definiera miljöprestanda knutet till en specifik teknik eftersom det är så starkt beroende av hur systemgränserna sätts. Om gränserna sätts för snävt är det lätt att missa helheten och vad som gynnar miljön i ett litet perspektiv kanske får motsatt effekt på miljön som helhet. Definitionen av ”Available” anser Jonson vara en sammanvägning av prestanda och ekonomi, dvs kostnadseffektivitet, som ska avgöra om den är tillgänglig. För forskningsrådets del är det snarare ett krav att de tekniker som tilldelas stöd inte är tillgänglig eftersom stöd ska delas ut till tekniker som ännu inte är kommersiella.

När det kommer till begreppet ”Techniques” var Tor tidigare skeptisk mot hela begreppet BAT eftersom T, då stod för ”Technology”. ”Technology” är en betydligt snävare definition än Techniques för vad begreppet omfattar. Då hamnar man i problemet med systemgränser och det finns risk för suboptimering som på sikt kan hämma innovation inom miljöområdet. Genom att gå över till den senare mer omfattande definitionen undviker man till viss del detta problem vilket Jonson tycker är ett steg i rätt riktning.

Jonson ser i dagsläget tre aspekter som extra betydelsefulla när det gäller miljöpåverkan från olje- och gasindustrin, utsläpp av CO_2, NO_x och utsläpp till havet, framförallt utsläpp av borrkax. Utsläpp av borrkax är emellertid i huvudsak förknippat med prospektering och borrning av brunnar och börjar på grund av stort tidigare stort fokus och utveckling ges mindre utrymme. För driften av en plattform är utsläppen till havet reglerade, övervakade och kan idag hanteras. Istället är det stort politiskt fokus på att reducera utsläppen av CO_2. Att jämföra olika miljöaspekter och prioritera dessa relativt varandra är inte något som forskningsrådet sysslar med i praktiken. Jonson tror det är svårt att göra detta på ett trovärdigt sätt utan att dras in i en politisk diskussion.

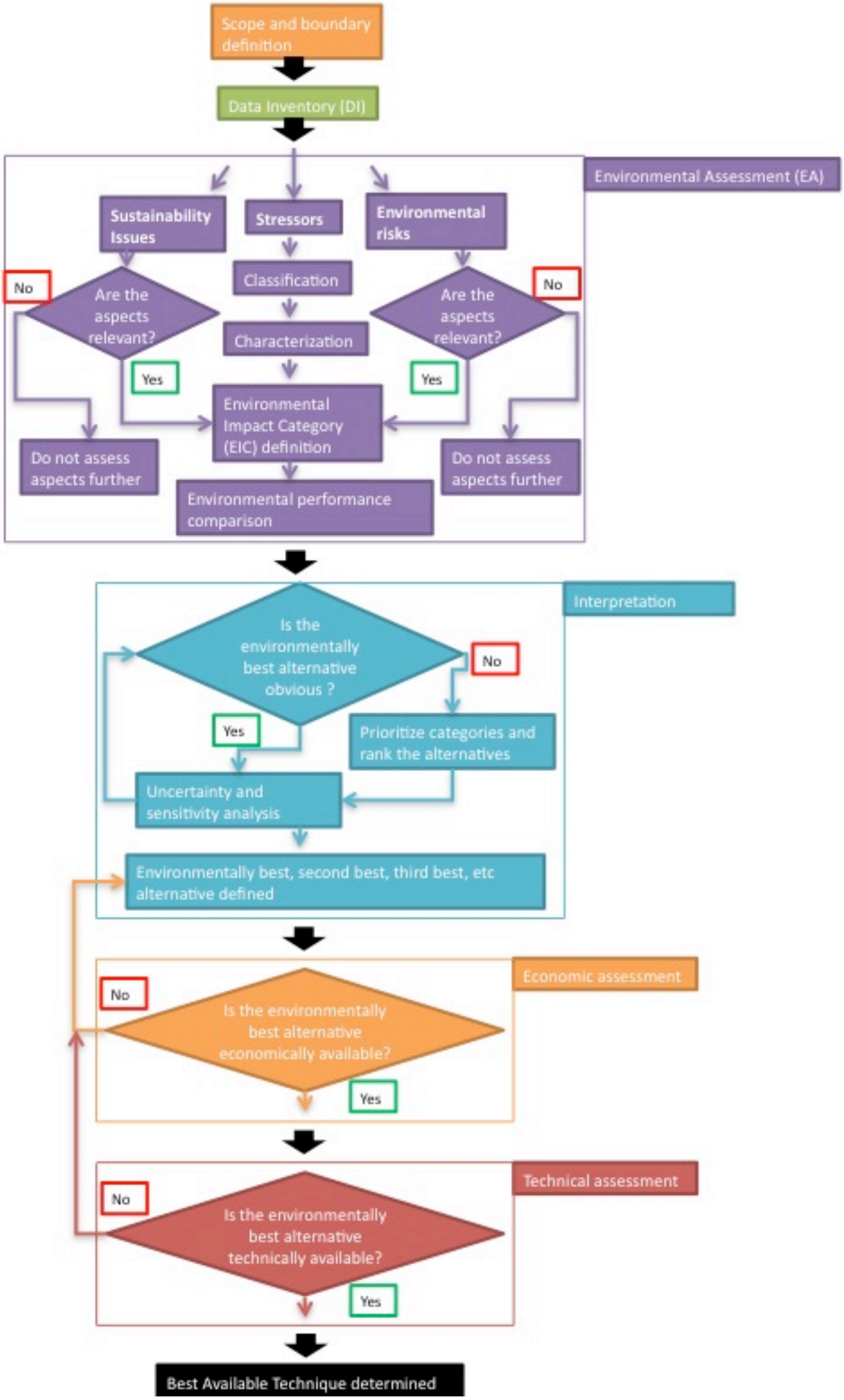
För att bedöma den ekonomiska tillgängligheten anser Tor precis som tidigare intressenter att kostnadseffektivitetsbedömningar är det bästa sättet. Att sedan relatera dessa till olika siffror är svårt och det blir snabbt politiskt. Tittar man på kostnadseffektivitet för åtgärder för att reducera CO_2-utsläpp inser man snabbt att det är mer lönsamt att göra åtgärder utanför Norges gränser och detta leder till än mer politisk kontrovers. Oljebolagens uppgift är att utvinna olja och gas och i detta är de generellt inte beredda att gå längre än att uppfylla de minimumkrav som finns. För att väsentligt minska utsläpp till luft och speciellt utsläpp av CO_2 måste avgifterna för att släppa ut bli betydligt högre. Först då kan tekniker som CCS bli intressanta i praktiken. Problemet med att höja avgifterna till sådana nivåer är att oljebolagen då helt enkelt anser att det bli för dyrt att utvinna olja på norsk sockel och istället söker sig till regioner som inte har lika stränga krav och gör utsläppen där istället.

På frågan huruvida BAT är ett känt begrepp i olje- och gasbranschen svarar Jonson att människor som direkt jobbar med miljö och miljöteknik generellt är bekanta med begreppet medan det är tämligen okänt vad det egentligen innebär för övriga.

Best Available Techniques – Guideline proposal for Det Norske Veritas

Summary

Best Available Techniques (BAT) is a principle defined in the Directive 2008/1/EC of the European Parliament on Integrated Pollution Prevention and Control (IPPC directive). In this guideline it has been interpreted chiefly as a tool to compare the environmental performance of different techniques. This guideline proposes a methodology for performing BAT assessments within the oil and natural gas industry and focuses on the operation of an offshore platform. The proposed methodology has been based mainly on an EU reference document and its structure has been inspired by typical LCA processes. The guideline structure is summarized in the figure below.


Scope and boundary definition
Data Inventory (DI)
Environmental Assessment (EA)
Sustainability Issues
Stressors
Environmental risks
No
Are the aspects relevant?
Classification
Are the aspects relevant?
No
Characterization
Yes
Yes
Environmental Impact Category (EIC) definition
Do not assess aspects further
Do not assess aspects further
Environmental performance comparison
Interpretation
Is the environmentally best alternative obvious ?
No
Yes
Prioritize categories and rank the alternatives
Uncertainty and sensitivity analysis
Environmentally best, second best, third best, etc alternative defined
Economic assessment
No
Is the environmentally best alternative economically available?
Yes
Technical assessment
No
Is the environmentally best alternative technically available?
Yes
Best Available Technique determined

4 Introduction

Best Available Techniques (BAT) as a concept originates in the EU framework Best Available Technology Not Entailing Excessive Costs (BATNEEC), which was introduced in the Air Framework Directive (AFD) (84/360/EC). The purpose of this was to limit the emissions from large industrial installations. In 1996 the BATNEEC concept was replaced by BAT as a result of the convergence of German and UK regulatory tradition in the EU directive on Integrated Pollution Prevention and Control (IPPC) (96/61/EC). The IPPC directive was updated and redefined in 2008 (2008/1/EC; EC 2010).

The purpose of the IPPC is to prevent and control pollution from the sectors listed in its Annex I: energy industries, production and processing of metals, mineral industry, chemical industry, waste management and other activities (2008/1/EC). The IPPC directive has been integrated in Norwegian regulation and in the industry standard NORSOK S-003 developed by the Norwegian Oil Industry Association (OLF) and Federation of Norwegian Industry (Norsk Industri) and published by Standards Norway (SN) (SN 2005). In article 12 of the IPPC directive BAT as a concept is defined:

> ’best available techniques’ means the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole… (2008/1/EC)

Also in article 12 of the IPPC directive, the individual terms of the BAT concept are defined:

> ’techniques’ shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
>
> ‘available techniques’ means those developed on a scale which allow implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;
>
> ‘best’ means most effective in achieving a high general level of protection of the environment as a whole (2008/1/EC).

In Annex IV of the same directive considerations to be taken in a BAT assessment are presented. These can be found in Table 1 along with an interpretation for this specific guideline. In this guideline the BAT concept is interpreted primarily as a tool to compare the environmental performance of alternative techniques where regard is also taken to the economic and technical aspects of the evaluated techniques. This is done in order to define one alternative as BAT. The economic and technical analyses, however, are not regarded as the principal aims of the assessment but are done in order to determine if the environmentally best alternative is available or not.

4.1 BAT assessments in practice

In practice BAT is used as a definition to distinguish one technique from several alternatives. A BAT assessment is performed in order to reach this decision. Within the Norwegian oil sector BAT assessments can be performed in the concept, pre-engineering (FEED) and detail engineering phases of a project. The project development process and its different phases are shown in Figure 1.

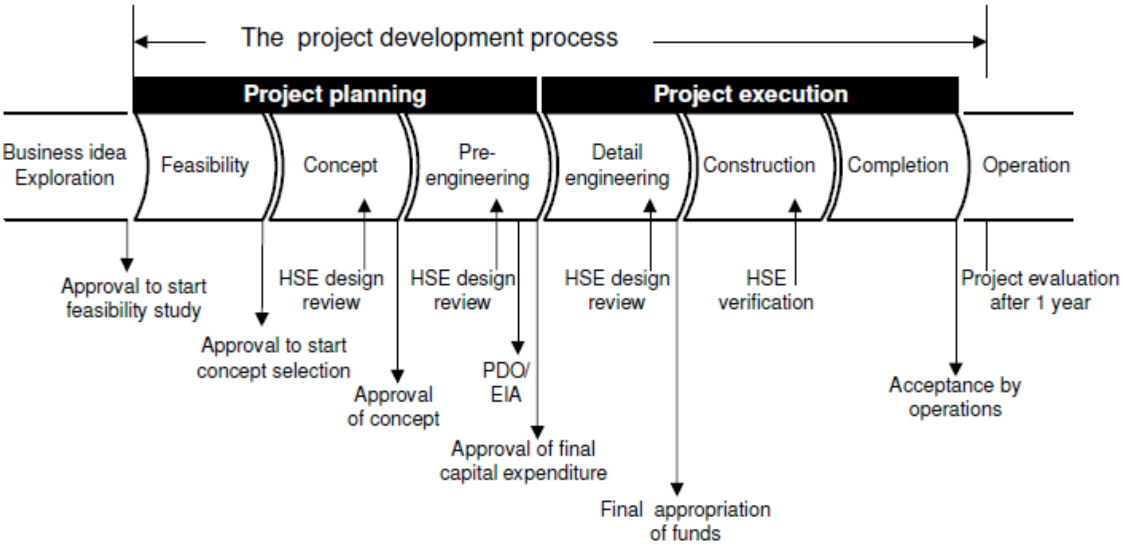


Figure 1 The project development process (SN 2005).

Most companies use formally defined project phases with decision gate processes when passing from one phase to the next. From a business perspective it is important to identify key environmental aspects in all project phases and to evaluate all possible concepts in order to avoid costly modifications at a later stage (SN 2005). Further the NORSOK standard recommends environmental design reviews in connection with concept selection, pre-engineering/Front End Engineering and Design (FEED) and during detail engineering. The most effective technical and/or operational solutions to this should be sought through the use of BAT assessments (SN 2005). Examples of environmental considerations in the different development phases are shown below.

Concept selection

Usually, BAT assessments are performed internally within the organization of the project owner, e.g. Statoil, but can also be done by external consultancy companies such as DNV (Kirkeng 2010). A few examples of environmental considerations to be taken are given in the NORSOK standard (SN 2005):

- Platform or subsea-to-land solution
- Power from land or from other platforms
- Transport solution for oil
- Reservoir drainage strategy
- Design for easy decommissioning

FEED

In the FEED phase the chosen concept is elaborated further to a level of detail and confidence that is required for deciding on execution strategy (SN 2005). In this phase the engineering contractor usually enters the BAT process (Kirkeng 2010). A few examples of environmental considerations presented in the NORSOK standard are given below (SN 2005):

- Main process design and energy balance
- Power supply configuration
- Identification of main chemicals
- Basic design of produced water treatment or injection system
- non-methane Volatile Organic Carbon (nmVOC) recovery system

Detail engineering

In this phase the design is further detailed until fabrication drawings can be issued. The key issue is to avoid changes from the basis already established in the FEED. From an environmental perspective it is important to evaluate how such changes influence the environmental performance (SN 2005). As with the FEED phase the BAT assessments at this stage usually take place at the engineering contractor through a close contact with suppliers (Kirkeng 2010). Some aspects that should be taken into account in this phase according to the NORSOK standard are:

- Complete evaluation, selection and documentation of chemicals used
- Detailed design of wastewater treatment systems and drain systems
- Detailed spill prevention issues

BAT should be a concept implemented throughout the project development process and involve many different parties. From the Environmental Impact Assessment (EIA), which is examined by the authorities, it should be clear that BAT assessments have been performed. In Norway the evaluation of the EIA is done by the Climate and Pollution Agency (Klif). Putting together the EIA, and making sure that BAT assessments of all included techniques have been done falls under the responsibility of the project owner (Kirkeng 2010).

4.2 Purpose

DNV has noticed an increasing demand for the performance of BAT assessments from their customers. As of today these are done, within DNV as well as in other organizations, in different ways and with different focus areas. Therefore, DNV has expressed a wish for a structured methodology for BAT assessments.

The purpose of this guideline is to present a methodology for BAT assessments to be used internally at DNV. It has been developed for DNV by two Environmental Engineering students from Lund University, Sweden, as part of their master thesis.

4.3 Method

Studying existing BAT assessments and methodologies has helped the development of this guideline. Experiences gained from doing two simplified fictitious BAT assessments have also played a large part in developing the guideline. A proposed methodology found in the IPPC Reference Document on Economics and Cross-Media Effects (ECM) has been influential in the development of this guideline. (2006). Also, interviews conducted with BAT experts from the different stakeholders have provided useful insight into BAT practise. These include representatives from government agencies, engineering companies, project owners and consultancy companies. Moreover, the structure of the guideline has been inspired by processes found in the Life Cycle Analysis (LCA) methodology outlined in the ISO 14040 standard series (2006).

4.4 General recommendations

As explained above BAT assessments are viewed as a tool for comparing the environmental performance of different technique alternatives. It is therefore assumed that the reader of this guideline has a background in the environmental sciences and a basic understanding of environmental issues, technology and terminology. Also, as this guideline has been developed for application within the oil and natural gas industry a basic knowledge of this field is recommended in order to understand the guideline.

All BAT assessments will hold a certain degree of subjectivity and this must be considered both in writing and studying them. Therefore transparency in every step of the decision process in the assessment is very important. Furthermore, all choices made must be clearly motivated; assumptions and simplifications must be explained.

If outside experts are contacted in order to perform engineering calculations that are used in e.g. the Data Inventory (DI) module, these should be referred to with name and position and/or experience level (Nyland 2010).

If, at any stage of the BAT assessment, the choice of technique becomes apparent the process may be stopped and all modules of the guideline will not have to be used. The choice will need to be motivated, and the underlying decision base presented in a transparent manner. The final aim of a BAT assessment is to evaluate alternatives to find what alternative is the best available technique.

4.5 Definitions

Assessor	The person(s) doing the assessment on Best Available Techniques
Available techniques	Developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced in the Member State in question, as long as they are reasonably accessible to the operator (2008/1/EC)
Best	Most effective in achieving a high general level of protection of the environment as a whole (2008/1/EC)
CO_2	Carbon dioxide
Environmental Assessment (EA)	The process of categorising and characterising the data gathered in the DI

Environmental Impact Category (EIC)	The effect on the environment caused by the emission/discharge of a certain stressor or sustainability issue or environmental risk
Environmental Impact Assessment (EIA)	Document that must be handed in to and be approved by authorities for all projects that may have a significant impact on the environment. This includes all offshore installation projects.
Interpretation	The process of analyzing the information in the EA
Data Inventory	The process of gathering information on a certain technique
NO_x	Nitrogen oxides, refers to NO and NO_2
Platform	The physical installation used for oil and gas production offshore, non-subsea, manned or unmanned
Rig	See platform
SO_x	Sulphur oxides, refers to one or more of various sulphur oxide compounds, mainly SO_2
Stressor	An emission or discharge, which leads to one or several environmental impacts
Techniques	May refer to both a technology and the way in which the installation is designed, built, maintained, operated and decommissioned (2008/1/EC)
Technology	Tools, machinery or a system of machinery created to fulfil a specific function

4.6 Abbreviations

AP	Acidification Potential
BAT	Best Available Techniques
CO_2	Carbon dioxide
DI	Data Inventory
DNV	Det Norske Veritas
ECM	IPPC Reference Document on Economics and Cross-Media Effects
EA	Environmental Assessment
EIC	Environmental Impact Category
EP	Eutrophication Potential
FEED	Front End Engineering and Design
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control

LCA	Life Cycle Analysis
nmVOC	non-methane Volatile Organic Compounds
NO_x	Nitrous Oxides
PM	Particulate Matter
POCP	Photochemical Ozone Creation Potential
SO_x	Sulphur Oxides

5 Structure of guideline

As can be seen in Figure 2 the guideline has been divided into 7 different modules, from scope and boundary definition to conclusion. Each module has been assigned a colour to indicate the change from one module of the guideline to the next.

In module 1 the scope and boundary of the BAT assessment are defined. In this module constraints are identified and the system boundaries are set in order to form the scope of the BAT assessment. In module 2, the DI, information is gathered of the techniques that fall within these constraints.

In module 3, the EA, the environmental data from the DI is divided into three categories; stressors, sustainability issues and environmental risks. The stressors are classified and characterized into EICs. Sustainability issues and environmental risks are evaluated and, if found to be relevant for the assessment, also included as EICs.

In module 4, the interpretation, the results of the EA are interpreted to determine which technique is environmentally best. To make this process as transparent as possible the guideline presents different methods to prioritize the EICs and to rank the alternatives in terms of environmental performance. The final step of the interpretation is to ascertain the results of the interpretation. This is done in an uncertainty and sensitivity analysis.

In modules 5 and 6 the economic and technical viability of the technique considered to be environmentally best is analysed. If these analyses conclude that the alternative is not available the process is repeated with the second environmentally best alternative.

In the conclusion the results of the different modules of the guideline are summarized and a recommendation on best available technique is given. Limitations in the result and recommendations for an extended evaluation may be presented here.

Table 1 below presents the requirements in the IPPC directive and how these have been interpreted in the guideline. It also shows in which guideline module these requirements will be dealt with. The purpose of the table is to show how the IPPC directive has been implemented in this guideline.

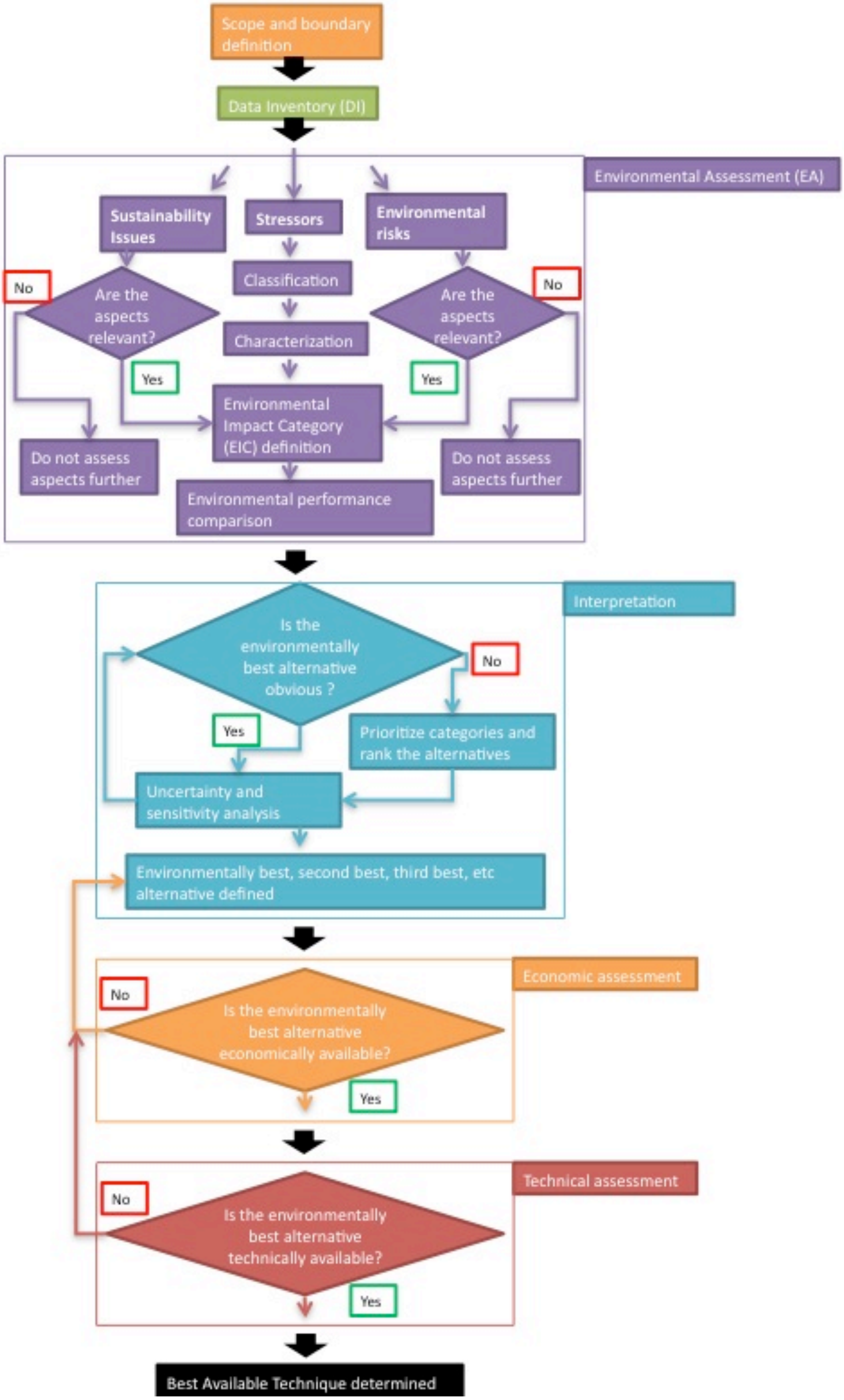
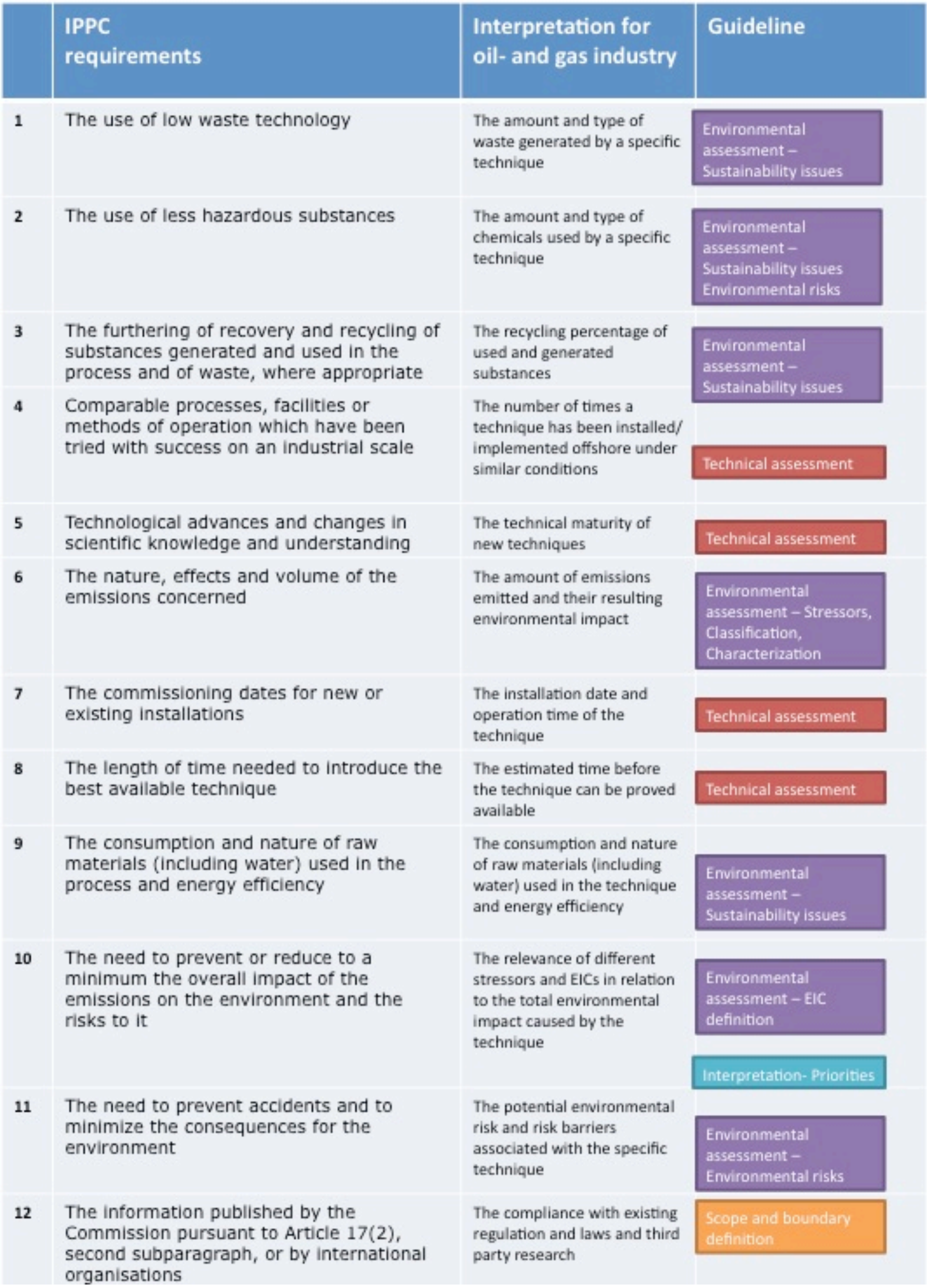


Figure 2 Structure of the guideline.

Table 1 IPPC requirements and guideline interpretation



	IPPC requirements	Interpretation for oil- and gas industry	Guideline
1	The use of low waste technology	The amount and type of waste generated by a specific technique	Environmental assessment – Sustainability issues
2	The use of less hazardous substances	The amount and type of chemicals used by a specific technique	Environmental assessment – Sustainability issues Environmental risks
3	The furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate	The recycling percentage of used and generated substances	Environmental assessment – Sustainability issues
4	Comparable processes, facilities or methods of operation which have been tried with success on an industrial scale	The number of times a technique has been installed/ implemented offshore under similar conditions	Technical assessment
5	Technological advances and changes in scientific knowledge and understanding	The technical maturity of new techniques	Technical assessment
6	The nature, effects and volume of the emissions concerned	The amount of emissions emitted and their resulting environmental impact	Environmental assessment – Stressors, Classification, Characterization
7	The commissioning dates for new or existing installations	The installation date and operation time of the technique	Technical assessment
8	The length of time needed to introduce the best available technique	The estimated time before the technique can be proved available	Technical assessment
9	The consumption and nature of raw materials (including water) used in the process and energy efficiency	The consumption and nature of raw materials (including water) used in the technique and energy efficiency	Environmental assessment – Sustainability issues
10	The need to prevent or reduce to a minimum the overall impact of the emissions on the environment and the risks to it	The relevance of different stressors and EICs in relation to the total environmental impact caused by the technique	Environmental assessment – EIC definition Interpretation- Priorities
11	The need to prevent accidents and to minimize the consequences for the environment	The potential environmental risk and risk barriers associated with the specific technique	Environmental assessment – Environmental risks
12	The information published by the Commission pursuant to Article 17(2), second subparagraph, or by international organisations	The compliance with existing regulation and laws and third party research	Scope and boundary definition

Figure 2 and Table 1 combines to give an overview of the methodology proposed in this guideline and what aspects need to be included in a BAT assessment in order to efficiently, transparently and uniformly define the best available technique.

5.1 Example and issue boxes

Throughout the guideline the text will give recommendations on the progress of the assessment. For clarification of the guideline text, short examples of assessment aspects will be given throughout the guideline.

Example boxes will be presented in textboxes with blue frames.

In some steps of the process straightforward recommendations will be difficult to give. In such cases a discussion with an interpretation may be necessary. "Issue boxes" will be used to discuss these aspects.

Issue boxes will be presented in textboxes with red frames.

In all, the structure will include recommendations in text, examples and issue boxes. Together they should provide the full guidance needed to create a BAT assessment. In order to exemplify the full guideline, two fictitious BAT assessments are presented in appendix A and B. They can be studied for further clarification of the guideline as a whole and for individual modules.

6 Scope & boundary definition

The first module of the BAT assessment is the definition of the system or concept that is to be evaluated. The scope and depth of the assessment is dependent on what stage in the project development process the BAT assessment is to be applied to as described in Figure 1.

6.1 Site specific conditions

An important aspect for any new installation is in which geographical area the system is to operate. This will determine which laws and regulations apply as well as define the regional environmental conditions at the site. For oil and gas platforms basic information such as distance from land and water depth shall be provided in order to provide the general design basis. According to IMO the MARPOL convention will be applicable for all offshore installations with a propulsion system or if a wet-tow to the site will be done. For the Norwegian continental shelf, the Barent Sea area has stricter environmental regulation.

6.2 Significant environmental impacts

According to the ISO 14001 standard that outlines the scope of environmental management systems an important step when launching such a scheme in an organization is to define the significant environmental impacts (2004). By doing this the planned measures can be focused on the significant environmental impacts in order to achieve the best protection for the environment as a whole. The same approach should apply to BAT assessments.

It can be very difficult to decide which environmental aspects are to be considered significant as this always will involve politics and/or the subjectivity of the assessor. In an attempt to identify the significant environmental aspects of oil and gas operation, BAT experts from four different stakeholders, including the Norwegian Climate and Pollution Agency (Klif), were interviewed during the development of this guideline. They all claimed that, as of 2010, the significant environmental aspects of Norwegian offshore oil and gas operation were emissions to air, especially CO_2 and NO_x, and discharge to sea, especially oil or oily compounds and other chemicals. This is motivated by the fact that current Norwegian policies focus on reducing emissions to air that can be linked with global warming and acidification. Oil and chemical discharge to sea has always been an important political issue as this severely may affect the local environment (Jonson 2010; Kirkeng 2010; Hoel & Sandgrind 2010; Åsnes 2010). It should be noted that the significant environmental impacts may change over time as a result of change in e.g. policies, new research and public opinion.

The significant environmental impacts aspects specified above should be given high priority in the BAT assessment. If one or more of these aspects are left out of the assessment this has to be motivated.

Issue – Significant environmental impacts
Nationally, the petroleum sector in Norway is accountable for 27 percent of CO_2-emissions, 28 percent of NO_x-emissions and 40 percent of nmVOC emissions (Norwegian Ministry of Energy and Petroleum (MEP) 2007). The large fraction of total emissions caused by the oil and gas industry makes it key in future reduction schemes.

In 2008 1660 tonnes of oil were discharged as planned operational discharges to sea from Norwegian offshore installations. The long term effect of discharging oil to sea is unknown and as a precaution it is thus important to reduce these discharges (OLF 2009).

If the guideline is implemented outside of Norway, regional/national conditions and political priorities may be different which could influence the significant environmental impacts. Since CO_2 and nmVOC emissions cause global environmental impacts they should always be given high priority. Emissions of NO_x and oily water are of a more regional nature and could, if this is not an issue in the vicinity of the emission source, prove insignificant. The recommendations on which environmental issues to prioritize should be handled with care by the reader. These priorities may change over time as a result of change in e.g. policies, new research and public opinion.

6.3 Constraints

The constraints that the studied system must comply with shall be defined in order to provide the assessor with a basis for screening of techniques, i.e. choosing a number of alternatives to study further.

6.3.1 Regulatory constraints

All laws and regulations applicable to the studied system shall be identified and stated. Company, group or industry requirements and standards shall also be identified.

6.3.2 Need & capacity constraints

In order to identify all possible techniques for evaluation and not exclude potential solutions, the need that the technique must satisfy shall be defined. In order to do this the assessors may ask the following questions:

- What is the purpose of the system?
- What task must be solved?
- What is the work that must be done?

Defining the actual need early in the assessment is very important as this sets the conditions for the technique screening, which will be carried out later. If the actual need is not defined early it can result in the BAT assessment being fixed to a certain technique and potentially overlook alternatives that may fulfil the need.

Example – Identifying the need
A reservoir used for oil extraction also contains large amounts of water. The mixture of oil and water is pumped up from the reservoir and separated on the platform. When discharged to sea the water must not contain more than 30 ppm of oil according to regulatory requirements. In some cases this mixture can be re-injected to the reservoir. The need is identified: *a system that can handle the discharge/re-injection of the expected amounts of water/oil in compliance with regulation*. With this broadly identified need many different types of techniques can be identified as suitable (e.g. injection back into the reservoir, biological cleansing, chemical cleansing and mechanical cleansing). As all these techniques possibly can satisfy the defined need they should all be evaluated further in the assessment.

Having identified the need of the system the assessor should identify the required capacity of the system. Ideally, when evaluating different alternatives, the capacity or size of the system should be fixed in order to ensure that the alternatives are compared on an equal basis. For practical reasons this may not always be possible and in such cases simplifications can be made. Care should be taken in order to do this with as great transparency as possible (ECM 2006). The exclusion of common factors shall be clearly stated.

Example – Identifying the capacity
The separation system on an oil platform should be designed for a handling *capacity of 20000* m^3 *oil-gas-water-mix/day*.

6.3.3 System boundaries

The scope of the assessment will have a large impact on the selection of system boundaries, and vice versa. System boundaries is a concept commonly used in the LCA methodology, but which is applicable in many other cases. In BAT assessments system boundaries will be useful to create a common basis for evaluation. This shall be done to ensure that the same environmental aspects of the compared techniques are included in the DI. According to the ECM the focus of the BAT assessment should be on the operation of the physical installation (2006). However, the IPPC directive states that certain aspects outside of the physical installation should be considered in order to determine their environmental significance. Such aspects may include the construction, installation and decommissioning of equipment.

In order to quickly evaluate where the largest impact of a technique occurs and if processes outside of the standard system boundaries are to be included in the EA an initial screening can be done at the start of the BAT assessment. This initial screening is performed qualitatively through applying the expertise of the assessor or interviewed experts. If there is time and such information is available a quantitative assessment with assigned scores in each category can be done. A fictitious example of the result of such a screening is provided in Figure 3.

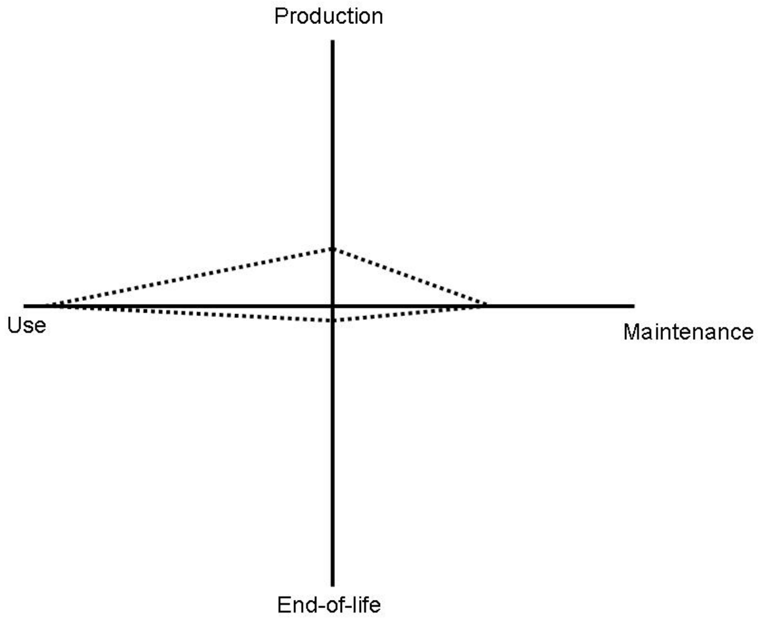


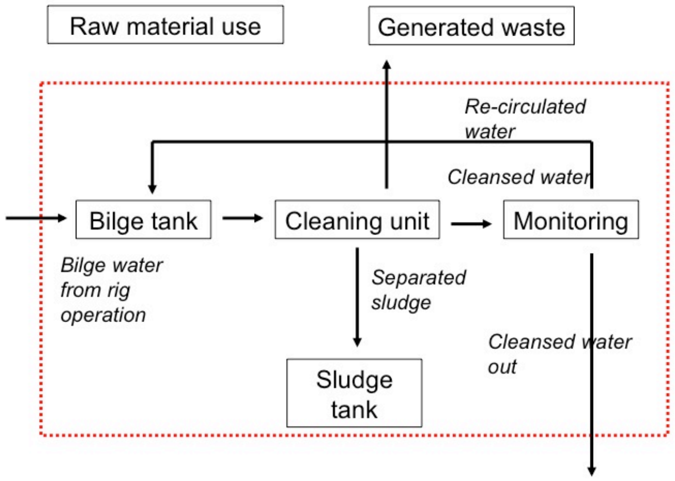
Figure 3 Initial screening of environmental impact of a product.

In Figure 3 the potential impact of a typical active product is described, i.e. its largest impact occurs in the use phase of its life cycle and secondly in the maintenance of the product.

In cases where the initial screening shows that the production and end-of-life phases have a potentially high impact the system boundaries must be extended from the physical installation to include these aspects.

In other cases where the production or end-of-life phases carry a potentially large part of the impact these must be explored in detail. Such analyses are included in the EA under 8.2 Sustainability issues.

Example – System boundaries
In the figure below the system boundaries from a bilge water treatment system are shown.



The boundary for the assessment is marked by the dotted red line. Processes (presented as boxes in the figure above) outside the system boundary are not included in the BAT assessment. Raw material has, in this case, been excluded from the study because it is assumed to be equivalent for all alternatives. Generated waste is excluded because it makes up such a small volume of the platform total.

Issue – Defining system boundaries
It may be difficult to define the system boundaries at an early stage of the BAT assessment. This specifically applies to BAT assessments that are done on a conceptual level with few details, and with technique alternatives that are very different. Defining the system boundaries can be an iterative process that allows the system boundaries to be changed as the assessment moves forward and the relevant processes become apparent.

6.3.4 Functional unit

With regards to the need and capacity constraints defined earlier, the LCA methodology, (ISO 14040) recommends the definition of a functional unit (2006). This unit will provide the basis for comparison of environmental performance between different alternatives. It should cover the need that is to be satisfied and must be measurable e.g. 1 kWh of electrical energy or the transport of 1 tonne 1 kilometre. (Rydh et al. 1997). EICs can be related to this unit when comparing them e.g. g CO_2/kWh produced or kg sludge produced/m^3 water cleansed.

It is recommended that a functional unit is defined in the BAT assessment before the evaluation of different techniques starts. However, in some instances the definition of a functional unit may not be possible. Such analyses may instead be based on a qualitative comparison basis.

Example – Functional unit
In the previous example the need was identified to be *a system that can handle the discharge/re-injection of the expected amounts of water-oil in compliance with regulation.* Based on this the functional unit can be defined as m^3 of discharged oil-water mix from the platform. Environmental impact categories can then be related to this unit, e.g. m^3 oil release to sea/m^3 of discharged oil-water mix from the platform or g emitted nmVOC/ m^3 of discharged oil-water mix from the platform.

7 Data Inventory (DI)

The second module of the guideline is the DI where techniques are identified and emissions or discharge from each evaluated technique are quantified within the previously defined system boundaries (ECM 2006).

7.1 Technique screening

The techniques that fall within the constraints specified in the previous module are considered. If it becomes apparent that any of the studied techniques do not satisfy these constraints they will fall out of the assessment process. It should be emphasized that both conventional and new techniques should be included in the technique screening so as not to exclude newer technique at this early stage of the BAT assessment. The IPPC Reference documents on BAT (BREF) regarding e.g. large combustion plants can be used to identify potential techniques within the constraints earlier defined (EC 2006). Data on the performance of the techniques that are to be studied is then collected.

A basic description of the technique shall be provided if this is necessary for the understanding of the BAT assessment. The BAT assessment should, if necessary for either the assessor or the target reader, contain a general theoretical description of the environmental impact of the technique (Sadiq et al. 2005).

7.1.1 Presentation of DI data

The gathered data for the different alternatives shall be presented. Data can be summarized for all alternatives or presented separately. It may be presented either in the form of a table, a figure or as text.

7.2 Data quality

Data of high quality is essential in a BAT assessment. The assessor should question and evaluate the quality and sources of used data. If the nature of the sources is not equivalent for the different techniques this should be emphasized. The ECM provides a list of possible sources including pilot studies, researchers and vendors/manufacturers. For the full list see the ECM (2006).

According to Rydh et al. the time and geographical relevance is also important (1997):

- Time relevance
  - Is there a maximum time limit for how old data may be? Over how long time period must data have been collected?
- Geographical relevance
  - Is the collected data applicable for the geographical area that the technique is evaluated for?

7.3 Uncertainty

To simplify the uncertainty and sensitivity analysis that is to be carried out later in the interpretation module of the assessment, the gathered data should early in the assessment be classified according to the level of uncertainty. Where quantitative uncertainties related to data are available, e.g. an emission level with a +/-10% confidence, these should be included in the uncertainty classification. Where no quantitative uncertainties are available the uncertainty classification can be done qualitatively according to the specific case.

One way of qualitatively estimating uncertainty in data is proposed by the ECM as shown below (2006):

A. An estimate based on large amount of information fully representative of the situation and for which all background assumptions are known.
B. An estimate based on a significant amount of information representative of most situations and for which most of the background assumption are known.
C. An estimate based on a limited amount of information representative of some situations and for which background assumptions are limited.
D. An estimate based on an engineering calculation derived from a very limited amount of information representative of only one or two situations and for which few of the background assumptions are known.
E. An estimate based on an engineering judgement derived only from assumptions.

If the rating system above is used all data sets are graded from A to E. The influence of the uncertainty on the result of the assessment is evaluated in the sensitivity and uncertainty analysis in the interpretation module.

Example – Uncertainty classification
A BAT assessment in the FEED phase of a development project evaluating different gas turbines was performed. The assessor had identified three turbines from three different suppliers that fulfilled the constraints defined. The gathered data was made up mainly of different emission values from operation of the three alternative techniques. To present the uncertainty of the data the assessor used the uncertainty classification method proposed above to assign a total uncertainty for data on both emissions of NO_x and efficiency. The table below shows the type of information given and the resulting uncertainty category.

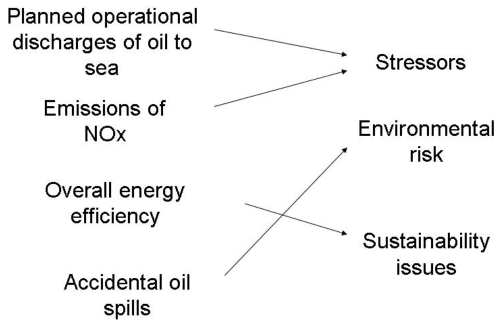
Alternative techniques	**Turbine 1**	**Turbine 2**	**Turbine 3**
Emissions of NOX	10 ppmv Values measured by supplier for an installation offshore with similar conditions	20 ppmv Values calculated by supplier using a computer program	25 ppmv No data provided by the supplier, values estimated by assessor from previous experiences
Efficiency	39 % Value measured under standard conditions running the turbine at full load	35 % Interval given +-20%	40 % Value given in a supplier brochure without detailed description of conditions
Resulting uncertainty category	B	C	D

8 Environmental Assessment (EA)

In the EA the environmental data from the DI is divided into three categories; stressors, sustainability issues and environmental risks. The stressors are classified and characterized into EICs. The potential sustainability issues and environmental risks are, if found to be relevant for the assessment, also defined as EICs.

Example – EIC types

Data from the IA is divided into stressors, sustainability issues and environmental risk. An example of data and how these are divided is shown in the figure below.



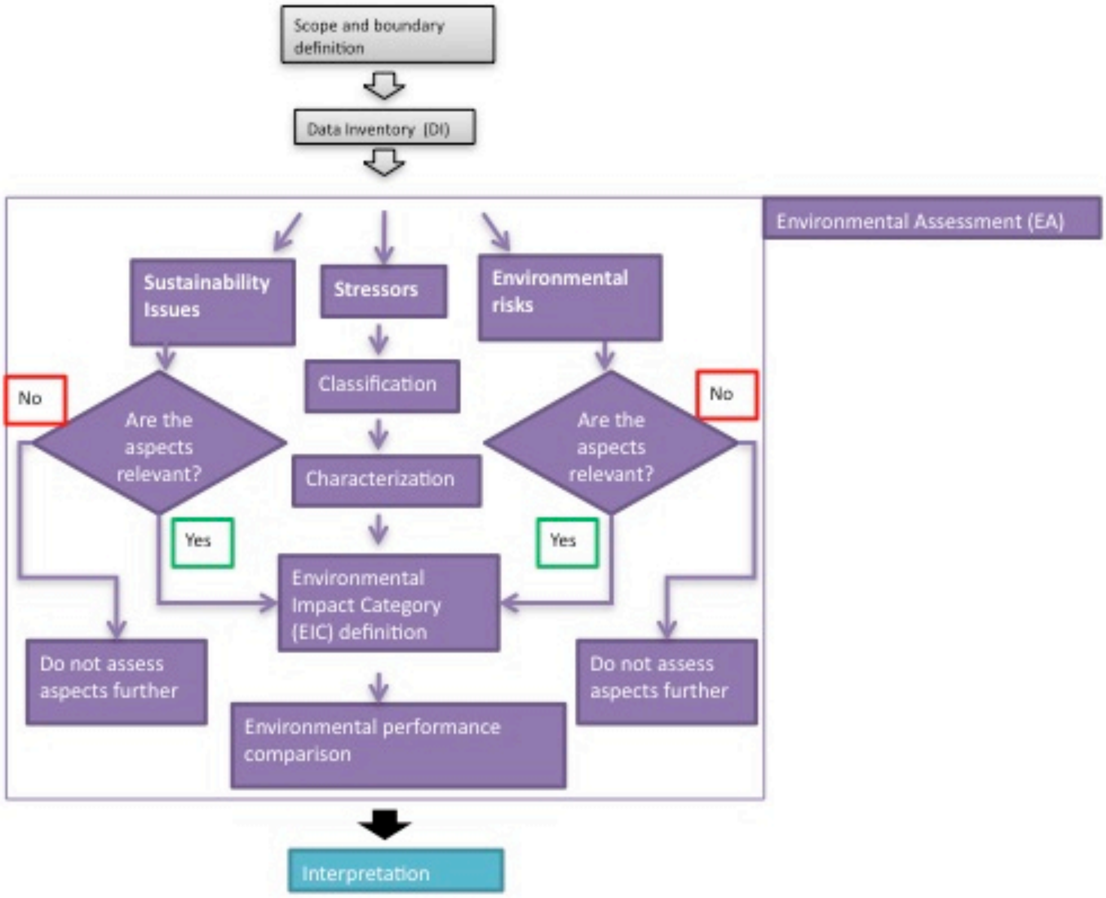


Figure 4 The Environmental assessment (EA) in the guideline structure.

8.1 Stressors

As previously defined, stressors are emissions or discharge of substances that leads to environmental impact. They shall be classified and characterized into EICs.

8.1.1 Classification of stressors

In order to assess the environmental impact that the emissions or discharge cause, they shall be classified into impact categories. This process includes identifying stressors such as CO_2 and organizing them according to their potential impact. Information on which stressors cause what environmental impact can be found in the ECM or any basic LCA guideline. E.g. CO_2, NO_x and CH_4 all have the potential to decrease heat radiation from the earth and cause global warming. A single stressor, e.g. NO_x, may have several potential impacts – in this case acidification, eutrophication, human toxicity and photochemical ozone creation potential (Sadiq et al. 2005, ECM 2006). An example of classifying common stressors is shown in the figure below.

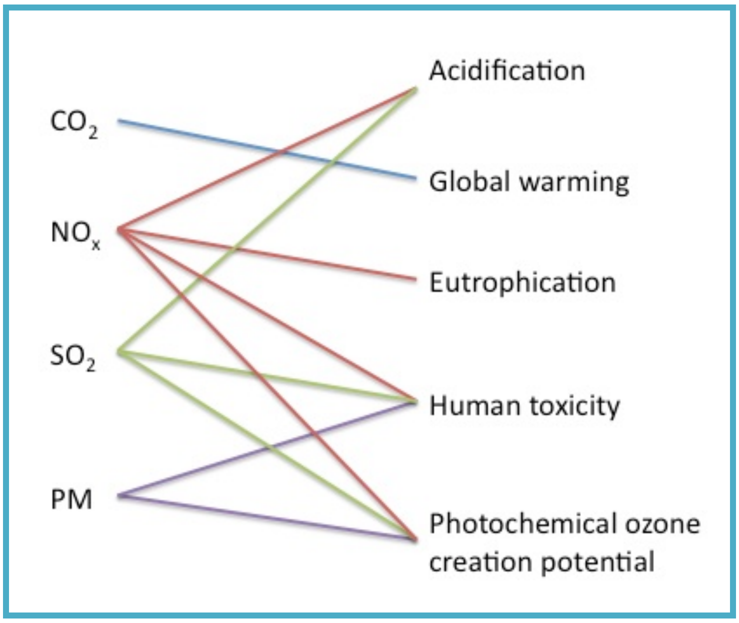


Figure 5 Example of the classification process

The number of classification (or impact) categories may vary with the studied technique, the boundaries of the assessment and the constraints as defined in module 1 scope and boundary definition. The ECM suggests seven environmental impact categories (EICs) that the stressors can be related to. The categories proposed are (ECM 2006):

- Human toxicity

Human toxicity is a way to express the relative harmfulness of a specific substance to humans. In the ECM all the listed toxic substances are assumed to enter the human body through inhalation. For oil and gas rig operations human toxic compounds can be gases from emissions to air like NO_x, SO_x and Particular Matter (PM).

- Global warming

GHGs in the atmosphere absorb outgoing heat radiation from the surface of the earth. The absorbed heat is re-emitted to the atmosphere. The net effect of this phenomenon is a warming of the atmosphere. Common GHGs are CO_2, methane (CH_4) and N_2O.

- Aquatic toxicity

The discharge of e.g. oil and chemicals may cause toxic effects, i.e. harm to organisms in oceans, lakes and rivers. Examples of such substances used in oil and gas rig operations are oily compounds, drilling chemicals and heavy metals.

- Acidification

The combustion of e.g. diesel and gas leads to emissions of sulphur and nitrogen compounds. These undergo chemical transformation in the atmosphere and are washed out with rain as sulphuric and nitric acid. When acidic compounds are deposited on the ground or in water they may lower the pH of the surrounding ecosystem. Such changes may have severe negative effects on the organisms of the ecosystem.

- Eutrophication

In lakes and oceans the growth of organisms is often limited by the phosphorus or nitrogen inflow. In e.g. agriculture, these compounds are used in fertilizers and end up in estuaries from where they can be transported to lakes and oceans. An increased inflow of fertilizers leads to an increased growth of microorganisms and toxic algae species. This phenomenon is known as eutrophication and may cause e.g. oxygen deficit, biodiversity degradation and other harmful effects for the ecosystem. Sources of phosphorus and nitrogen are e.g. combustion of fossil fuels, fertilizers and discharges from wastewater treatment plants.

- Ozone depletion

The emission of certain gases, e.g. freon, cause catalytic reduction of ozone which creates holes in the ozone layer of the uppermost layers of the atmosphere. The ozone layer filters out harmful UV radiation being emitted from the sun. Overexposure to UV radiation may cause certain forms of cancer in humans and abnormal mutations in other organisms. In oil and gas rig operation ozone depleting substances can be found in climate controlling facilities as heat pumps and refrigerators where these are used as cold/heat-transfer mediums.

- Photochemical Ozone Creation Potential (POCP)

Certain gases that are emitted from mainly combustion are in the presence of direct sunlight transformed into ozone in the lower atmosphere where it affects both humans and nature. Ozone is toxic when inhaled and causes e.g. cancer and also damage the cell walls of green plants. In oil and gas rig operations POCP stems from emissions of NO_x, CO and PM from combustion processes.

Not all studied techniques will cause emissions that can be related to all of these categories. Many of them, end-of-pipe solutions in particular, will address only one or a few. The selection of relevant stressor EICs shall be stated and motivated in order to maintain the transparency and simplicity of the assessment. Other EICs, such as sustainability issues and environmental risk will be dealt with in 8.2 and 8.3.

The effects of some stressors may be unclear due to insufficient or conflicting research. In such cases quantification of the environmental impact may not be possible and a qualitative evaluation may be done instead.

8.1.2 Characterization of stressors

This step will characterize the data processed in the classification step. This can be done in mainly two ways depending on impact category. When considering global warming, acidification, eutrophication, ozone depletion and photochemical ozone creation potential, individual pollutants can be converted to an equivalent reference substance using multiplication factors. The calculation is shown in the equation below.

EIC (kg reference equivalents) = [stressor (kg)] **X** [multiplication factor (kg reference equivalents/ kg stressor)]

Common multiplication factors can be found in the annexes of the ECM. It should be noted that these might vary with the chosen time horizon (ECM 2006). Once all stressors in an impact category have been characterized according to the reference equivalent they are summarized to present the total impact in each category. The alternatives can then be evaluated in terms of their total impact in the stressor EICs. Table 2 shows where in the annex to find the multiplication factors for the respective EICs and their equivalent substance.

Table 2 The relation between EICs, their equivalent substance and multiplication factors

EIC	**Eqvivalent substance**	**Multiplication factors**
Global Warming	kg CO_2	Found in ECM Annex 2
Acidification	kg SO_2	Found in ECM Annex 4
Eutrophication	kg PO_4^{3-}	Found in ECM Annex 5
Ozone depleting potential	kg CFC-11	Found in ECM Annex 6
Photochemical ozone creation potential	kg Ethylene	Found in ECM Annex 7

Example – Characterization using multiplication factors

In the energy production example an alternative using a combined gas turbine cycle was found to emit 1928 tonnes of NO_X during the project lifetime. According to Figure 5 NO_X emissions can be related to four EICs; acidification, eutrophication, human toxicity, and photochemical ozone creation potential. In the characterization the NO_X emissions should be characterized by the equivalent substances in each EIC. Characterizing human toxicity is principally different from the other EICs and will be dealt with in the next example. The process of characterizing the other three EICs is shown in the table below using multiplication factors from the annexes in the ECM.

EIC	Acidification potential	Eutrophication potential	Photochemical ozone creation potential
Multiplication factors	0,5	0,13	1,815*
Resulting amount equivalents	1928 x 0,5 = 964 tonnes SO_2	1928 x 0,13 = 250,6 tonnes PO_4^{3-}	1928 x 1,815 = 3499 tonnes Ethylene

**This value has been calculated by taking the mean of the values -0.06 and 3.8 stated in the annex 7 of the ECM*

As seen in the table the stressor NOX is converted to the reference equivalents of the three EICs by multiplying the total mass of emitted NOX with the multiplication factors.

Issue – Multiplication factors

For some stressors there exist several conflicting multiplication factors. To some extent this can be related to different researchers making different assumptions. Where such conflicts exist, the assessor should make the choice of multiplication factor as transparent as possible, motivate it and account for any assumptions that may provide the theoretic basis behind the calculated multiplication factor.

In order to characterize EICs such as aquatic- and human toxicity, a different method must be used. For these two EICs the characterization can be done by dividing the mass of the toxic stressor by the toxicity threshold of the pollutant. This gives the volume of air or water needed to dilute the pollutant to a safe level. Then the amount of air/water needed to dilute different stressors related to a specific alternative is summarized. This volume of air/water is thus a measure of the relative toxicity and can be used to compare the environmental performance of the alternatives. The equation below shows the calculation described above.

Amount of air or water (m^3) = [mass of stressor (kg)] **/** **[**toxicity threshold of stressor (kg/m^3)]

The way to define toxicity threshold when dealing with aquatic toxicity, proposed by the ECM, is to give the toxicity threshold in "Predicted No Effect Concentration" (PNEC). PNEC means a concentration where no toxic effect can be detected. PNEC- values for substances commonly released to water can be found in Annex 3 of the ECM (ECM 2006).

Another method to determine the human toxicity level is to use the toxicity threshold presented in Annex 1 of the ECM. The values are derived from German exposure limits for a number of toxic substances commonly released to air. These values are presented relative the toxicity factor of lead i.e. all threshold values presented are divided by the toxicity threshold of lead. The result presented in Annex 1 of the ECM is a list of dimensionless toxicity factors and the calculated human toxicity is given in mass lead equivalents. Relating the toxicity to lead is not necessarily an approach that must be used when comparing human toxicity. However, if the values listed in Annex 1 is used it should be noticed that these are scaled with the toxicity of lead.

Example – Characterization of human toxicity
In the energy production example an alternative using a combined gas turbine cycle was found to emit 1928 tons of NO_X and 1223 tons of CO during the project lifetime. Both of these stressors can be related to human toxicity. The table below shows how the stressors are characterised to determine the human toxicity.

Stressor	NO_X	CO
Mass of pollutant (tonnes)	1928	1223
Toxicity factors of the ECM Annex 1 (tonnes/tonnes lead eq)	95*	350
Calculated mass of corresponding lead equivalents (tonnes lead equivalents)	1928/95 = 20,3	1223/350 = 3,5
Total human toxicity of the alternative in lead equivalents (tonnes lead equivalents)	**23,8**	

In this case the human toxicity was calculated in lead equivalents and was found to be 23,8 tonnes. This number can then be used to compare the other alternatives evaluated in the assessment.

**NO_x is in this example simplified to NO_2*

Issue- Characterization
There are several simplifications and uncertainties inherent in the characterization methodology proposed. Some of these are listed in the annexes of the ECM along with the values. It should be noted that the methodology is only to be used when comparing alternatives and not to define the absolute impact in a certain environmental impact category. Strictly speaking one substance is not completely interchangeable with another through the use of a multiplication factor. The effects of individual substances are more complex than this simplification. However, when comparing alternatives such numbers can be used to get a broad overview and to clarify the differences between the evaluated alternatives. This approach is regarded as sufficient for BAT purposes.

When applying the proposed methodology it may prove difficult to find representative values for all stressors in the ECM annexes. In such cases other databases may be used. If no representative values can be found, the assessor can evaluate the alternatives qualitatively based on available information and experience.

8.1.3 Cut-off

Any effects or emissions that are considered to be of insignificant importance to the assessment may be disregarded. This is consistent with the so-called cut-off rule of the LCA methodology, which states that the assessor may define a cut-off value of e.g. 10% of environmental impact in each defined EIC. Any emission below this in each EIC may be excluded from the DI/assessment. Care should, however, be taken to declare and justify the cut-offs made in order to maintain the transparency of the assessment (ECM 2006; Rydh et al. 1997).

8.1.4 Presentation of stressor EICs

Having done the characterization, the information previously gathered is summarized and presented as EICs.

Example – Characterization from energy production
In this example a presentation of characterization results for different energy production technologies are given. The functional unit in this example was the production of 5 TWh of power and 3 TWh of heat.

	Hydropower	*Nuclear power*	*Wind power*
AP (ton SO_2 eq)	117	407	373
GWP (kton CO_2 eq)	42	24	84
EP(ton PO_4 eq)	5	20	26
POCP (ton C_2H_4 eq)	73	294	381

Above the impact from three alternative energy production techniques are shown in four different EICs. In this case the EICs deemed as relevant were Acidification Potential (AP), Global Warming Potential (GWP), Eutrophication Potential (EP) and Photochemical Ozone Creating Potential (POCP).

8.2 Sustainability issues

The aspects in this section are closely related to the initial screening done in 6.3.3. If this initial screening has shown that the production and/or end-of-life phase(s) will have a large influence in the environmental performance of the technique they shall be evaluated as an EIC in this section. Other such aspects that are to be evaluated in this section, if they have a potentially large impact, are raw material use, waste generation and energy efficiency. The choice to include or exclude these issues in the BAT assessment will have to be clearly motivated by the assessor.

8.2.1 Waste

In accordance with the IPPC directive the BAT assessment should keep generated waste at a minimum by using low-waste technologies and techniques that promote the recovery of waste and recycling. The ECM proposes a division of wastes into three categories that can be expressed in mass of waste produced (ECM 2006):

- Inert waste

Waste that does not undergo any significant physical, chemical or biological transformations. Inert waste will not dissolve, burn or otherwise physically or chemically react, biodegrade or adversely affect other matter with which it comes into contact in a way likely to give rise to environmental pollution or harm human health (1999/31/EC).

- Hazardous waste

In order to be classified as hazardous waste, the waste must have one of the following properties: explosive, oxidizing, highly flammable, flammable, irritant, harmful, toxic, carcinogenic, corrosive, teratogenic, mutagenic, ecotoxic (91/689/EEC).

- Non-hazardous waste

Waste that does not have any of the properties listed above.

8.2.2 Raw material use

As discussed in the initial screening raw material use could prove an important environmental impact parameter. If the result from the initial screening is unclear or if it has been shown that the construction/raw material use should be included in the assessment it will, in most cases, be sufficient with a set of simple questions to assist in choosing manufacturers with a lower ecological footprint. Such questions may e.g. be (Christiansen 2010):

- Is the manufacturer certified according to ISO 14001?
- How is the material/equipment transported?
- Does the manufacturer use any hazardous materials?
- Does the manufacturer use “design for recycling”?
- Where does the raw material originate?

For the scope of BAT assessments such a general evaluation should be sufficient in most cases. If, however, it has been shown that raw material use must be explored in greater depth the nature of the used material will be an important parameter. Obviously, the more recycled or renewable material used the less the impact on the environment will be. The type of material used is also important, metals and specifically steel will normally have a high impact compared to organic materials. Resources such as coal, oil, and natural gas also have a significant environmental impact in their extraction phase.

Example – Raw material use

When comparing different techniques for bilge water treatment, stainless steel was identified as the main material in the components. The steel used was virgin material with a considerable environmental impact. Therefore, raw material use was considered an important parameter to explore. As all evaluated alternatives were made mainly of steel the total weights of the alternatives were used as an EIC.

8.2.3 Energy efficiency

Energy efficiency is often an important parameter as the platform and its many subsystems use significant amounts of energy. A system with high energy efficiency puts a high percentage of the consumed energy into actual work, minimizing energy losses. Energy efficiency comparisons are more relevant in BAT assessments that focus on subsystems. Subsystem alternatives will often use the same type of energy, which means that energy efficiency often equals energy consumption.

In a conceptual BAT assessment, with alternatives that are very different, the meaning of energy efficiency is more complicated. Energy sources and energy carriers could differ and therefore it is important to include the whole process chain from energy efficiency in the first energy production/extraction stage, transport of energy, and finally efficiency in the consumption stage. The most relevant comparison in such a case is the total amount of primary energy needed.

Example - Energy efficiency in energy production concepts
In the energy production example the total energy efficiency, from fuel extraction to energy consumption for 5 different energy production concepts was evaluated. The main components of the concepts are described below.

1: Full electrification from shore of the platform.
2: Electrification from shore to cover power demand and offshore gas fired heaters to cover heat demand.
3: Electrification from shore, gas turbine with waste heat recovery to run the export gas compressor, gas fired heaters to cover the rest of the heat demand.
4: All energy supplied by offshore simple cycle gas turbines with waste heat recovery.
5: All energy supplied by a combined gas turbine cycle with waste heat recovery.

Energy efficiency	***1***	***2***	***3***	***4***	***5***
Primary energy used (EJ/FU)	33	32	35	56	48
Main sorce of energy	Hydro power	Hydro power	Natural gas	Natural gas	Natural gas
Energy efficiency	82 %	85 %	78 %	49 %	56 %

The table presents the total amount of primary energy consumed during the project lifetime, the main kind of primary energy used and the resulting total energy efficiency.

Issue – Energy efficiency
Regardless of what kind of fuel a technique consumes it is essential that the consumption is efficient. This can be motivated by the fact that if the same fuel was consumed somewhere else with the same purpose and higher efficiency, the impact there would be lower. This means that the total environmental impact on the environment as a whole would be lower. Drawing on this it can be claimed to be environmentally sound to use natural gas as a fuel on an offshore installation if the alternative use of the gas would imply combustion with lower efficiency, e.g. in a car engine.

8.2.4 Decommissioning

Decommissioning is for most techniques in BAT assessments of minor importance when compared to the environmental impact from the operation phase. However, decommissioning could prove important if the technique generates large amounts of hazardous waste when decommissioned, or if the process demands large amounts of energy. Also, the impact from decommissioning is not expected to differ significantly between the techniques. Therefore, this aspect normally is not included further in an assessment.

8.2.5 Local effects and footprint

In a general guideline it is challenging to take into account local effects that may arise from emissions and physical installations. All local environments are unique in their ability to handle pollution and stress and therefore they will have to be evaluated on a case-by-case basis. For any individual process detailed dilution and dispersion models may have to be developed. Other sources of pollution and the combined effect of the new technique and these may need evaluation. On a local scale odour, noise and vibrations will also have to be taken into account (ECM 2006). Also, decommissioning could affect the local environment and this must, in some cases, be considered. The process of evaluating local effects may prove complex and this issue falls slightly outside the scope of a BAT assessments, where it will only have to be addressed in a general sense. A full evaluation of local effects should instead be provided in the environmental impact assessment (Haukebø et al. 2010).

8.2.6 Presentation of sustainability EICs

A summary of the findings in the sustainability issues section is presented as EICs. This means that the relevant issues are presented in the same form as the stressor EICs in a table such that they can be compared in the same manner as these.

8.3 Environmental risks

The EICs may at this point include one or several of the seven impact categories proposed above as well as one or several sustainability issues. Besides these environmental risks can be included as EICs if environmental damage as a consequence of irregularities or accidents is considered a viable risk. A basic analysis that describes what risks the technique carries and what barriers there are to prevent these can be done. A risk matrix can be constructed in order to present these results. Also, previous environmental risk assessments can be used as input in this section.The results should then be summarized in a table in the same manner as the original EICs and the sustainability issues above.

8.4 Summary of EICs

The last step in the EA is to summarize and present all of the relevant EICs, i.e. the stressor EICs as well as sustainability issues and environmental risk, in the same table such that they may be compared on an equal basis in the following interpretation phase of the BAT assessment.

Example – Summary of EICs

In the table below an example of a summary of included EICs is shown. In the first four rows stressor EICs are presented and in the last row a single sustainability issue – energy efficiency – has been included. Of course, such a summary may include many sustainability issues as well as a quantitative or qualitative estimation of the environmental risk.

	1	2	3	4	5
AP (ton SO_2 eq)	129	372	587	1112	964
GWP (kton CO_2 eq)	65	788	1488	3070	2654
EP(ton PO_4 eq)	6	73	140	289	251
POCP (ton C_2H_4 eq)	95	1029	1984	4089	3533
Energy efficiency	82%	85%	78%	49%	56%

9 Interpretation

The following module of the BAT assessment aims to define which of the evaluated techniques is "best for the environment as a whole". This shall be done with regards only to the environmental performance of the system; economic and technical aspects will be considered in modules 5 and 6.

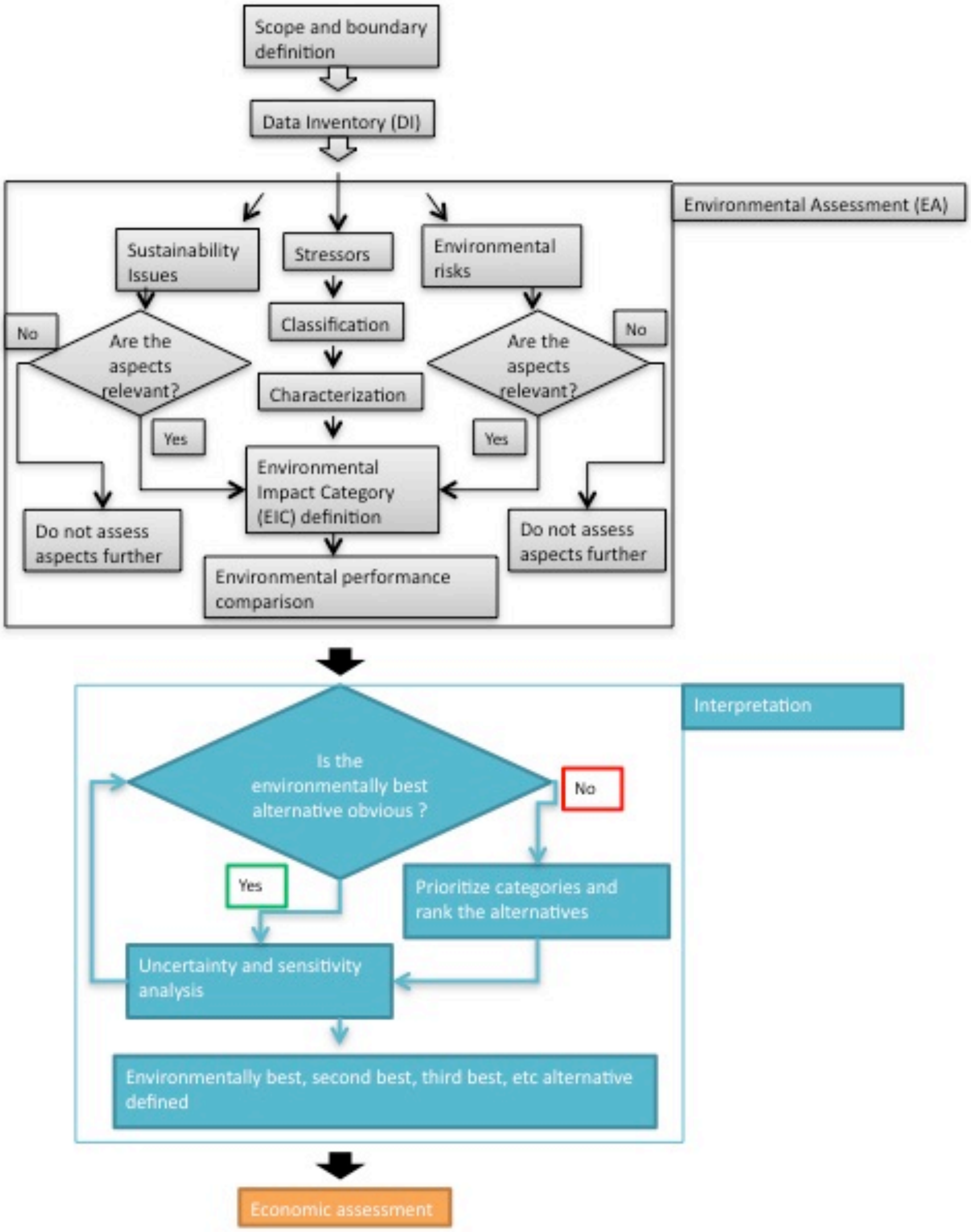


Figure 6 Interpretation in the guideline structure.

In this guideline several methods to prioritize the EICs and to rank the alternatives are presented. The assessor may choose the method he/she deems most suited to the situation. It is key to make this choice as transparent as possible and to evaluate the choice of technique, using e.g. sensitivity/uncertainty analysis where different approaches are tested. If the result from the EA is clear, i.e. it is apparent which of the techniques are environmentally best, no further investigation is needed. If the result from the EA is more complex, e.g. different alternatives being environmentally best in different EICs, the assessor should carry out the priority and ranking processes.

9.1 Priorities

Because there may be many EICs to evaluate the assessor will need to prioritize between these in order to choose one technique that is environmentally best.
Below a few methods of prioritizing between different EICs are presented.

9.1.1 Comparison with platform total

One mean of prioritizing the EICs is to relate emissions or discharge in each category to the total emissions or discharge from the platform. This can be presented as a share of the total emissions level for the platform. The results from this evaluation can be used to prioritize the category that has the largest share of the emissions.

Example – Comparison with platform total
In a BAT assessment of bilge water treatment systems two EICs were used: the amount of oil discharge and energy consumption. It was found that the oil discharge corresponded to 8% of the total discharge of oil to sea from the platform. The energy consumption for the bilge water treatment system was found to be 0,05% of the platform total. The conclusion from this evaluation was thus that oil discharge should be given a higher priority than energy consumption.

9.1.2 Comparison with national total

Similarly to the priority method described above emissions and discharge from the studied system can also be compared to the national total in the specific EIC if such a comparison is relevant.

9.1.3 Qualitative evaluation of priorities

In some assessments prioritizing different EICs may prove difficult due to e.g. highly varying properties between the evaluated techniques. In such cases it may prove more feasible to conduct a qualitative assessment of the effect of each EIC. Such an assessment may include regional environmental conditions, expert opinions as well as the relationship between platform/sector/regional/national emissions.

Example – Qualitative evaluation of priorities
In a BAT assessment of offshore energy production technologies CO_2 emissions were given the highest priority. This was motivated by the close relationship between GHG emissions and energy production, the global nature of such emissions and the opinions of experts interviewed in connection with the assessment . For a closer look at this example see appendix XX.

Issue – Difficulties in using priorities methods
In a BAT assessment of energy production for a platform both electrification and offshore energy production was considered. Depending on the electricity mix used for the electrification alternative, i.e. how much coal power that was included, the SO_2 emissions varied considerably. In such a case it proved difficult to use the comparison with the platform/national/EU totals since different electricity mixes would lead to different priorities. In such cases a qualitative evaluation is more viable.

9.2 Ranking

The final goal of the BAT assessment is to recommend one of the alternatives as BAT. Therefore, the studied alternatives must be differentiated from each other. This is done by ranking them in terms of their environmental performance. In this section a few ranking methods are suggested. Their suitability will change according to the specific situation.

9.2.1 Relative ranking

Relative ranking is a simple and straightforward way of comparing different alternatives and ranking them relative to each other. This can be done in two ways (Sadiq et al. 2005; ECM 2006):

- First, second, third best in each category – internal ranking
- Ranking according to a reference value, e.g. a mean or median value, industry standard or mean, platform or national total – reference ranking

Internal ranking is very easy to carry out but does not give any information on the magnitude of the difference between each alternative. Therefore, a discussion will be necessary to reach a conclusion and motivate the choice or recommendation made (ECM 2006). Reference ranking may require some additional data to be gathered and some standard calculations but makes it easier to compare the alternatives' performance relative each other.

Example – Internal ranking
Below the alternative techniques A-D are ranked in the four EICs. In each category the alternative with the best performance receives a (1) also shown in the table, the second best receives a (2) etc. This ranking method clearly shows which technique is best in each EIC.

	System A (rank)	***System B (rank)***	***System C (rank)***	***System D (rank)***
1. Reduction rate (ppm)	7,5 (2)	5 (1)	15 (3)	5 (**1**)
2. Energy use, power and steam (kWh/m^3)	Elec: 2,5 Steam: 69 (4)	50 (3)	5 (2)	2 (**1**)
3. Steel used in production (kg)	1510 (2)	2000 (3)	1000 (**1**)	950 (**1**)
4. Generated waste in operation	Sludge (**1**)	Sludge (**1**)	Sludge + filter change every 18-24 months (2)	Sludge + sand filter change every 24 month+dry waste (2)

The interpretation of these results would be to recommend alternative D as environmentally best as it is ranked first in three of the four EICs and second in the last.

Example – Reference ranking
In the upper table the calculated impact in the three EICs, Acidification Potential (AP), Global Warming Potential (GWP), and Eutrophication Potential (EP) are shown for the alternative techniques A-C. The last column of the upper table shows a given industry mean value in each of the three EICs. In the lower table the given industry mean values are used to scale the performance of the alternatives.

	System A	*System B*	*System C*	*Industry mean*
AP (g SO2 eq/kWh)	0,058	0,074	0,030	0,060
GWP (kg CO2 eq/kWh)	0,410	0,555	0,350	0,450
EP (g PO4 eq/kWh)	0,013	0,008	0,011	0,015

	System A		*System B*		*System C*
AP	97 %	(2)	124 %	(3)	50 %
GWP	91 %	(2)	123 %	(3)	78 %
EP	87 %	(3)	53 %	(1)	73 %

In the AP category, system C scores is the best performer with half (50%) of the mean. System B lies 24 % over the mean, and system A is only 5% under. In the lower table the result is clarified by putting (1), (2), and (3) after the best, second best, and third best alternative. If the result of the table above is interpreted alternative C should be deemed environmentally best as it scores highest in two of the three EICs.

9.2.2 Independent number ranking

In independent number ranking, the techniques are given scores according to their performance in each EIC. The score criteria can be constructed in several ways, e.g. through creating intervals **quantitatively** or **qualitatively** (Sadiq et al. 2005).

A quantitative interval can be created in a number of ways. One way is to use a statistical method where the intervals are created from mathematical parameters derived from the used data. Such statistical parameters can be; mean value of the evaluated techniques, median, number of alternatives etc. These can be combined to create suitable intervals for comparison.

Intervals can also be defined qualitatively based on e.g. the closeness in the numbers of the alternatives in each category. Once the intervals are defined the corresponding scores should be determined.

Issue – relative vs independent number ranking
Relevant ranking can be said to be merely another way of presenting the results from the EA. Independent number ranking, on the other hand, has a higher degree of aggregation and interpretation. Therefore, it should be stressed that transparency and motivations are very important in this method.

Example – Quantitative independent number ranking

In the energy production example five alternative techniques were compared in four defined EICs as shown by the table below. Also, the priorities of the EICs had been set as outlined below.

	Priority	***1***	***2***	***3***	***4***
GWP (kton CO2 eq)	**1**	3391	2868	3229	3070
EP(ton PO4 eq)	**2**	108	135	194	289
AP (ton SO2 eq)	**3**	480	562	779	1112
POCP (ton C2H4 eq)	**4**	1504	1900	2729	4089

To find the environmentally best technique the five alternatives were ranked in the four EICs. In this case a quantitative independent number ranking method was used. First the intervals were created in each comparison category. This is done by dividing the mean value of the alternative techniques in each category by the number of alternatives. This gives the step length for the intervals. The derived statistical data and the step length are shown in the table below.

	Max	**Min**	**Average**	**Interval step**
(1) GWP	3391	2654	3042	608
(2) EP	289	108	195	39
(3) AP	1112	480	779	156
(4) POCP	4089	1504	2751	550

The calculated intervals are shown in the table below.

	interval 1	**interval 2**	**interval 3**	**interval 4**	**interval 5**
(1) GWP	<608	608-1217	1217-1825	1825-2434	>2434
(2) EP	<39	39-78	78-117	117-156	>156
(3) AP	<156	156-312	312-468	468-623	>623
(4) POCP	<550	550-1100	1100-1650	1650-2200	>2200

Now that the intervals have been defined the corresponding score in each interval must be decided. In this example we chose a simple approach where the first interval was awarded 1 point, interval 2, 2 points etc. Thus low impact gives a low score and the alternative with the lowest score in each EIC is environmentally best. The result of the ranking is shown in the table below.

Ranking	**1**	**2**	**3**	**4**	**5**
(1) GWP	5	5	5	5	5
(2) EP	**3**	4	5	5	5
(3) AP	**4**	**4**	5	5	5
(4) POCP	**3**	4	5	5	5

As shown by the table above all alternatives score the same in the EIC with the highest priority; GWP. In the EIC with the second highest priority, AP, alternative 1 scores best and alternative 4 scores second best. In the third EIC, alternatives 1 and 2 were both awarded 4 points and in the last EIC alternative 1 scores best with 3 points and alternative 2 second best with 4 points. With the chosen ranking method it is obvious that alternatives 1 and 2 are better in terms of environmental performance compared to the other alternatives. According to these results, the environmentally best alternative should be alternative 1 as this is ranked best in three of the four EICs.

Example – Qualitative independent number ranking
In this example a qualitative method of creating intervals based on the performance of the evaluated techniques was used by the assessor. In this example two EICs were used to compare the four evaluated techniques (A-D). The two EICs were divided into five intervals. Each interval was assigned a score and then the different techniques could be given scores. The scores were summarized and are shown in the last row of the table below.

	System A	*Score*	*System B*	*Score*	*System C*	*Score*	*Syste D*
1. Reduction rate (ppm)	12	3	3	5	20	1	
2. Energy use, power and steam (kWh/m3)	48	1	27	3	11	4	
Total		**4**		**8**		**5**	

1. *<5 ppm = 5 p; 5 - 9 ppm = 4 p; 10 - 14 ppm = 3 p; 15 - 19 ppm = 2 p; >20 ppm = 1 p*
2. *<10 kWh/m3 = 5 p; 10 - 19 kWh/m3 = 4 p; 20 - 29 kWh/m3 = 3 p; 30 - 39 kWh/m3 = 2 p; >40 kWh/m3 = 1 p*

The technique scoring highest in each category is the environmentally best. The total score can be used to further interpret the result in the evaluated EICs. In the table above system B and D are candidates to be the environmentally best technique as these score highest in one respective EIC. Which one is defined as best will depend on which of the categories *Reduction rate* and *Energy use* that is prioritized highest. If the categories would be given the same priority you can argue that system D should be deemed best as this alternative has the highest total score.

Issue – Independent number ranking
While this system may help bring to light the magnitude of the differences between the studied techniques it can prove difficult to determine the criteria that the scoring is to be based on. Some techniques may vary so much in their performance that the creation of such a ranking system will become irrelevant. In such cases it is more feasible to use internal ranking.

9.3 Sensitivity and uncertainty analysis

In this section the uncertainty and sensitivity in the calculated result, i.e. in the defined environmentally best alternative, will be evaluated.

Uncertainty of a parameter comes from estimations and assumptions in information gathered. It also covers how applicable the information is in the specific situation where it is to be used. Uncertainty as specified in 7.3 should, together with potential uncertainties in the EA module, be listed. As described in 7.3 this is a qualitative process, which aims to organize the gathered data into uncertainty categories, which are listed below (ECM 2006):

A. An estimate based on large amount of information fully representative of the situation and for which all background assumptions are known.
B. An estimate based on a significant amount of information representative of most situations and for which most of the background assumption are known.
C. An estimate based on a limited amount of information representative of some situations and for which background assumptions are limited.

D. An estimate based on an engineering calculation derived from a very limited amount of information representative of only one or two situations and for which few of the background assumptions are known.
E. An estimate based on an engineering judgement derived only from assumptions.

A parameter that has high sensitivity has significant influence on the final result. If a parameter with high sensitivity is changed it is likely that the final result will change considerably. In the BAT-assessment calculations, priority setting, ranking etc. should be evaluated to find potential parameters with high sensitivity.

Parameters with high sensitivity and a high uncertainty are defined as key parameters and should be investigated further. The process of identifying the key parameters is illustrated in Figure 7 below.

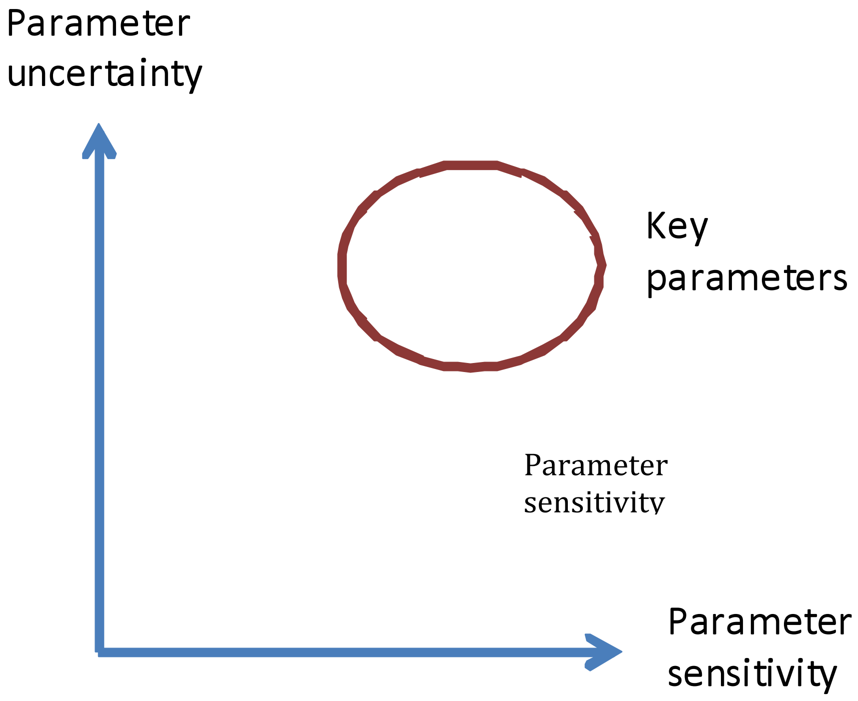


Figure 7 Identification of key parametres.

The red circle in Figure 7 indicates the area of the key parameters. If no such parameters are found this should be stated and the sensitivity and uncertainty analysis may be stopped. If key parameters have been identified the analysis should continue by evaluating how the results change if these parameters are altered within a certain interval. For quantitative parameters this can be done by varying with +/- 10%. For parameters where this is not possible, e.g. when evaluating methods of prioritizing and ranking, the chosen method should be altered. When varying one parameter all other parameters should be fixed.

When all key parameters have been appraised in this manner the result of the sensitivity analysis is evaluated and discussed to decide whether or not this affects the results of the interpretation.

Example – Sensitivity analysis of a chosen method
In a BAT assessment of energy production for an oil and gas platform two alternatives were evaluated: energy production on the platform and electrification of the platform. The emissions caused by the electrification alternative had high uncertainty and varied greatly with the electricity mix chosen i.e. hydro power, nuclear power, coal power etc. The selection of electricity mix also had a major influence on the final result and thus high sensitivity. Therefore, a case with the most probable electricity mix was created to serve as baseline case. In the sensitivity and uncertainty analysis the contribution of various energy sources were altered to investigate what impact this had on the final results. This is an example of a typical sensitivity analysis.

Example – Quantitative sensitivity and uncertainty analysis
This example is a proposal for how a sensitivity and uncertainty analysis can be performed. The example is an extension of the example done in 7.3.

Three alternative gas turbine techniques were compared. Emission data on NO_x and efficiency had been given and the data uncertainty had been classified according to the method proposed in 7.3. The uncertainty classification and the given values are shown in the table below.

Alternative techniques	**Turbine 1**	**Turbine 2**	**Turbine 3**
Emissions of NO_x	10 ppmv	20 ppmv	25 ppmv
Efficiency	39 %	35 %	40 %
Resulting uncertainty category	B	C	D

In the environmental assessment performed by the assessor global warming and acidification were identified as important aspects and were therefore defined as EICs chosen for comparison. When calculating the emissions from the operation of the turbines the efficiency was identified to be an important parameter as this value influenced the emissions of CO_2 and NO_x and thus both EICs. Therefore, the efficiency of the turbine was identified as a parameter with high sensitivity.

According to the table above the data of turbine 3 was categorised as a D in the uncertainty classification. As category D is the second lowest in the uncertainty classification, values in this category can be said to have a high uncertainty.

As the efficiency for turbine 3 is both uncertain and has a high sensitivity it is identified as a **key parameter**.

The sensitivity and uncertainty was further evaluated using the following method. The efficiency of turbine 3 was varied with +/-15 % while all other factors remain constant. The lower end of the interval gave the efficiency 34 % (40*0,85 = 34) and the higher, 46 % (40*1,15 = 46). Of these two values the lower value is the most likely as 46 % efficiency of a single cycle gas turbine is extremely high.

All calculations are now re-evaluated using the efficiency 34 % for alternative C. If the conclusion of the EA is different when using 34 % instead of 40 % for turbine 3, the analysis has shown that there is a significant uncertainty in the result. To reduce this uncertainty the assessor should try to attain data of higher quality for the defined key parameter. If this is not possible the uncertainty and sensitivity of turbine 3 must be highlighted in the results.

10 Economic Assessment

The purpose of the economic assessment is to give the assessor an idea of what type of costs can be accepted by the project owner and from this conclude if the technique is economically available or not.

In the economic assessment proposed in the guideline the technique considered to be environmentally best is analysed to see if it is available. If the analysis shows it is not, the alternative is dismissed and the process is repeated with the second environmentally best alternative etc.

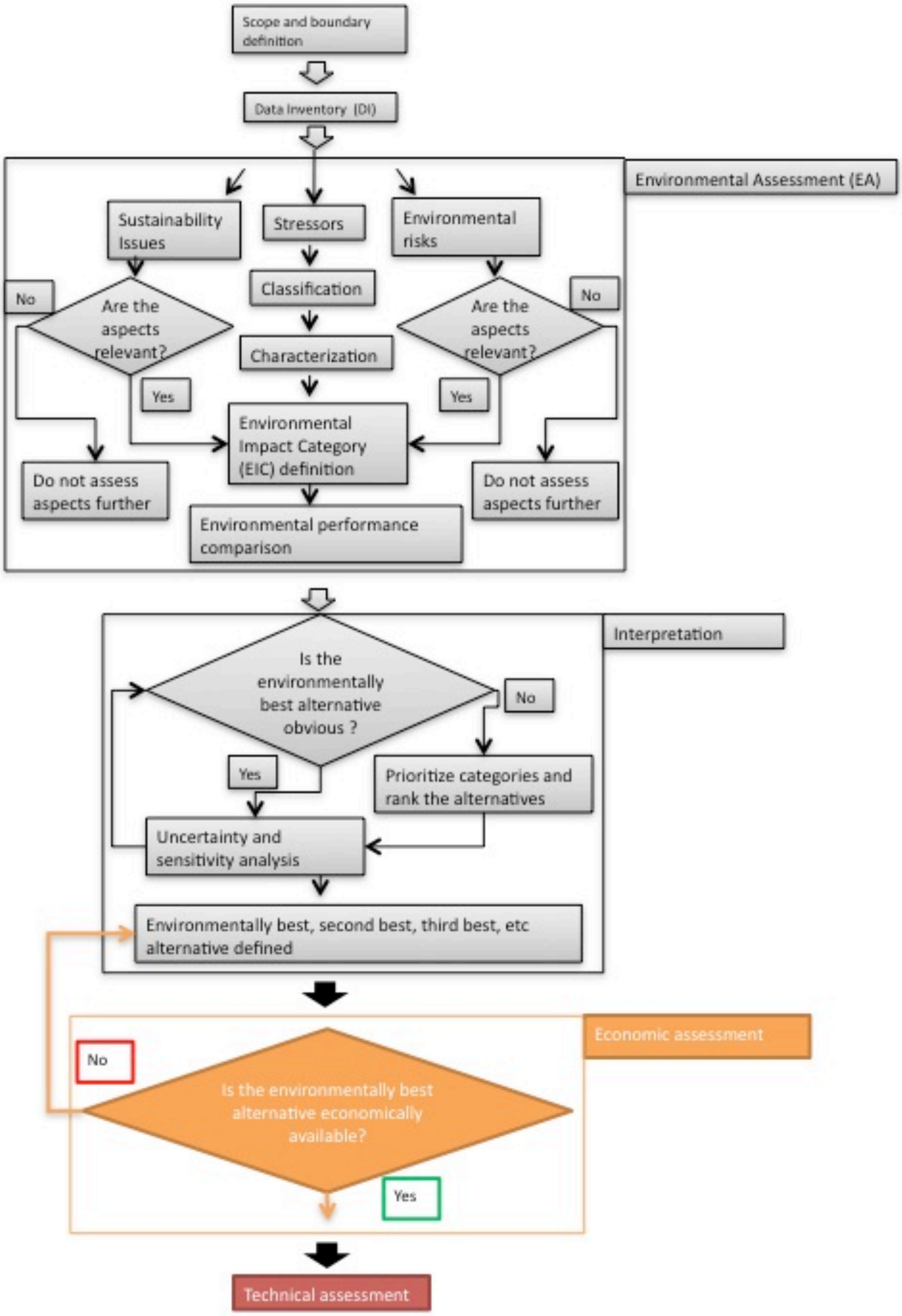


Figure 8 The economic assessment in the guideline structure.

An evaluation of economic viability is part of a BAT assessment. However, an in-depth analysis should only be carried out if there is genuine concern over which techniques can be implemented with economic feasibility. Such analyses shall be carried out on an industry sector level when new technology is introduced that leads to fundamental changes in the relevant sector. These studies fall outside the scope of the BAT and should be carried out as a separate analysis (ECM 2006).

Example – Economic assessment
Carbon Capture and Storage (CCS) for flue gas treatment offshore would bring a fundamental change to the oil and gas industry and therefore an extensive economic assessment is necessary.

If one of the parties deems the technique economically unfeasible, the burden of proof shall lie with the party raising the concern (usually project owner). They will have to motivate raising the concern and carry out the actual analysis (ECM 2006).

Below follows a few suggestions on how the economic assessment can be done. The methods used here are not the only possible methods but should be seen as an indication on the analysis depth required.

10.1 Cost efficiency

The economic assessment recommended is an evaluation of cost efficiency meaning cost per unit of EIC reduced. The cost efficiency can be related to either reference prices or historical developments (see 10.1.1 and 10.1.2). Often techniques that emit less pollutant will cost more than a conventional technique. The extra cost of the abatement can be related to the stressor(s) in two ways.

- All of the extra cost that the low-emitting technique causes is allocated to one stressor, e.g. CO_2.
- The extra cost of the low-emitting technique is allocated between the reduced stressors, e.g. 50% to CO_2 abatement and 50% to NO_x abatement.

What method to choose can be decided by what priorities have been used in the interpretation phase. If, for example, CO_2 is prioritized much higher than any other stressor the first method is the obvious choice. If both CO_2 and NO_x have been given high priorities in the interpretation and an allocation method has already been used the second method is a sound choice.

10.1.1 Cost efficiency in relation to reference prices

One way of relating cost efficiencies is to compare them with reference prices/costs. For a typical end-of-pipe solution the cost efficiency can be expressed as cost per mass of stressor reduced. Reference prices can for example be taxes for emitting certain substances like CO_2, NO_x and SO_x, i.e. NOK/ton CO_2, NO_x and SO_x.

If the proposed installation has significantly higher cost efficiency than the reference price level, i.e. a lower cost per g stressor reduced, it can be argued that the technique is economically viable. From a macro-economic perspective this approach is supported by the fact that taxes usually are meant to include external costs such as negative environmental effects. However, certain environmental effects such as impact on the local environment are difficult to estimate and other methods may have to be used when there are no reference prices.

Example – Reference prices
According to the Norwegian Climate and Pollution Agency (Klif) the combined CO_2 tax and CO_2 quota cost for the offshore industry is, as of 2010, approximately 400 NOK/ton CO_2 emitted (Hoel & Sandgrind 2010).

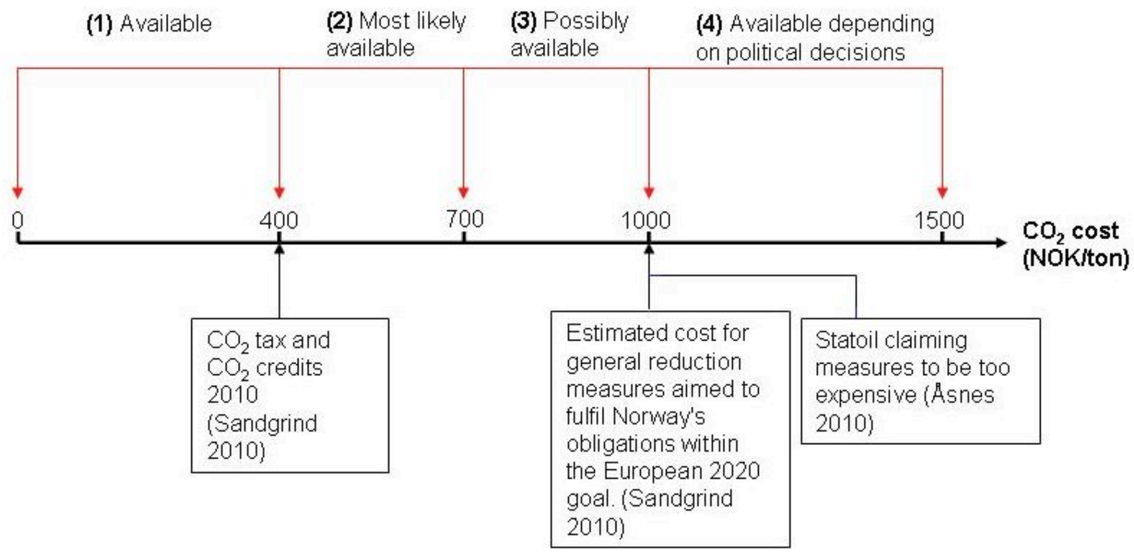
10.1.2 Cost efficiency in relation to historical developments

Relating the costs or cost-efficiencies of the studied alternatives to historical installations that have similar purposes and installation conditions is another means of determining their economic viability. In such a case general numbers for cost-efficiency can be used to compare costs for environmental impact reduction measures. Preferably these should have been installed under similar conditions and be expressed in the form of cost efficiency i.e. cost per environmental impact parameter (NOK/g stressor). It is also possible to base this analysis on general abatement costs for e.g. CO_2-reduction or eutrophication mitigation strategies, if such figures are accessible. The assessor should, however, reflect on the applicability of such costs to the studied system.

Example – Cost efficiency in relation to historical developments
According to Klif measures to reduce NO_x emissions have historically cost up to 50 NOK/kg NO_x reduced. Companies often use an “accepted” cost of 10 NOK/ kg NO_x (Hoel & Sandgrind 2010). This does not mean that only technologies with lower costs than this are considered to be BAT. It should, however, provide an indication of the type of cost that can be accepted.

Example – Cost efficiency in relation to reference prices and historical developments

The figure below shows how reference prices and information from historical developments can be used to relate cost efficiency to economic availability for CO_2 emissions.



Above is shown a cost efficiency range from 0-1500 NOK/ton CO_2. It is divided into four intervals (1)-(4). Evaluated techniques with a calculated cost efficiency could, according to the information presented from Klif and Statoil be deemed available using the four defined intervals. With these intervals techniques with cost efficiencies lower than 1500 NOK/ton (i.e. >1500 NOK/ton) can be dismissed as economically unavailable. Techniques with higher cost efficiency cannot be dismissed without further motivation.

10.2 Installations under similar conditions

If the technique has been installed before under similar conditions it can be argued that it is economically viable to install because another project owner has deemed it so. This method can be used if reference prices cannot be found or if the assessor wishes to use a simple and quick analysis method.

11 Technical Assessment

In the interpretation module one technique is defined as the environmentally best alternative. In the economic assessment module the economic viability of this alternative is evaluated. If found unfeasible the second best alternative is evaluated and so on. As in the economic assessment, the technical assessment is carried out to determine if the alternative is available or not. If the analysis shows it is not, the alternative is dismissed and the process is repeated with the second environmentally best alternative etc.

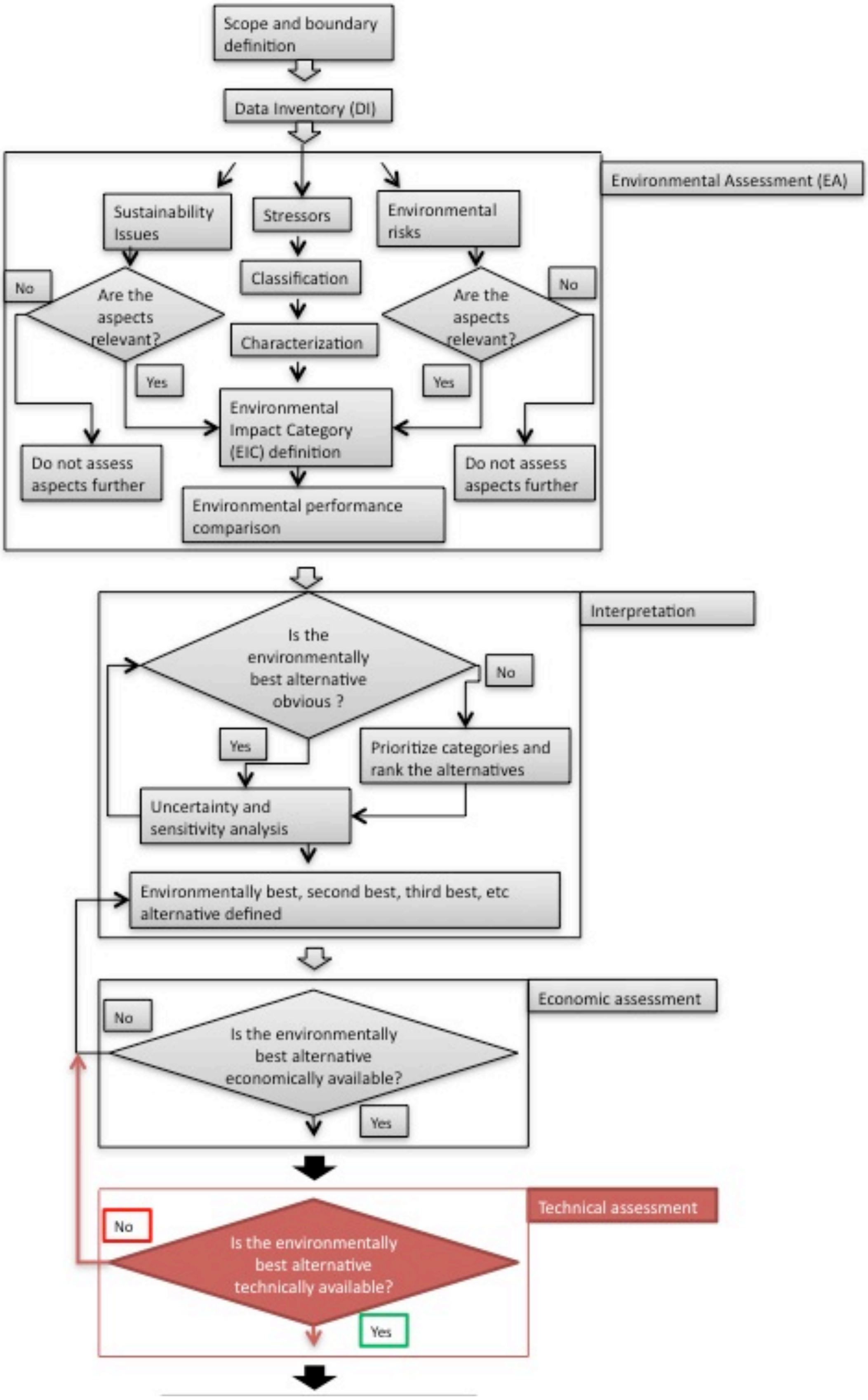
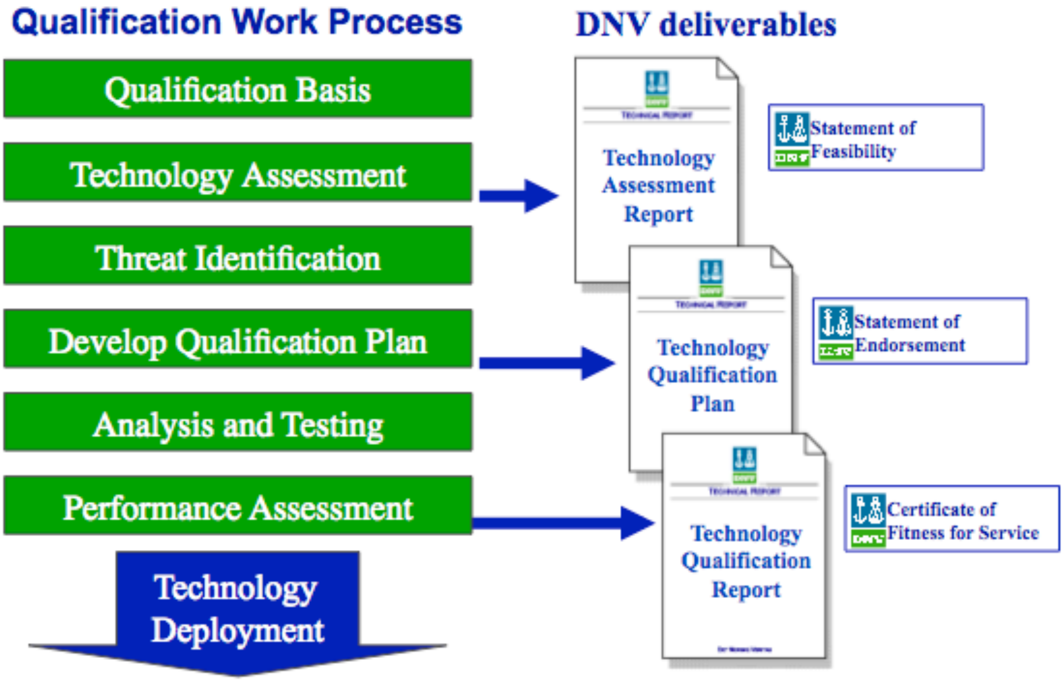


Figure 9 The technical assessment in the guideline structure.

The IPPC directive states that available techniques mean those "developed on a scale" that can be implemented in the relevant sector (2008/1/EC). However, it is the intention of this guideline to promote new technology and the definition of "technically viable" shall therefore be broadened to include newer technology.

New technology provides potential for cost savings and increased value of investment. However, it also raises the risk. In order to manage the risk that comes with unproven, new technology and to certify its technical viability for the company it has to be qualified to function within their specified limits. The minimum level of development that can be said to be "technically viable" will in this guideline be defined as complying with the DNV qualification stage *Fit for service,* or complying with an equivalent qualification stage.

In order for a technology to be deemed *Fit for service* by DNV it must have completed the following stages:



The definition of *Fit for service* is, according to DNV-RP-A203: "A technology is considered fit for service when the failure modes that have been identified through the systematic process outlined in this OSS have been properly addressed, and the supporting evidence substantiates that the technology fulfils all stated functional requirements and meets the stated reliability target".

For detailed information on the elements of the qualification process, see DNV-RP-A203.

11.1 Proven technology

One way of being deemed "technically viable" shall be a screening of existing applications. If the technology, meaning either the supplier-specific system or an equivalent, has been installed and used successfully under similar conditions by a similar operator/company it shall be considered to be technically viable (Kirkeng 2010).

If the technique has not undergone a technology qualification process or been installed under similar conditions offshore, a deeper analysis of this system must be done. Such an analysis must review what components of the technique that are new. The risk of these components should be evaluated and how they affect the whole system. At DNV such an evaluation can be done by, or in collaboration with, technology qualification experts (Remseth 2010).

12 Conclusion

Having gone through the three different assessment modules: interpretation, economic and technical assessment, a recommendation on what is the best available technique shall be given. The conclusion shall provide the customer with one recommended alternative.

12.1 Conditions for implementation

As a last step in the BAT assessment the assessor may state a few conditions for the implementation of the recommended technique. Besides absolute requirements that must be met in order to feasibly use the technique, these may include requirements for modifications of other equipment or processes. There may also be recommendations for further investigations necessary of the concerned or related process(es). This section may also discuss possible limitations in the performed assessment (Nyland 2010).

13 Diskussion

Den första delen av frågeställningen behandlade hur man praktiskt utvecklar en metodik enligt de krav och regler som omfattar driften av en olje- och gasplattform. En första svårighet vi stötte på var hur vi skulle utveckla en metodik som beskrev en process vi själva aldrig genomfört. Det kan ifrågasättas om detta är en rimlig uppgift att utföra som ett examensarbete eftersom vår uppgift var att utan praktisk erfarenhet skapa ett praktiskt verktyg. Vi hanterade detta genom att först sätta oss in i de direktiv och dokument som definierade och beskrev BAT och sedan studera redan utförda BAT-värderingar. Som tidigare nämnts fann vi dessa otillräckliga i förhållande till det definierade begreppet, vilket bidrog till hur frågeställningen utformades.

För att bygga upp en metodik ansåg vi att praktisk erfarenhet av processen krävdes. Därför bestämde vi oss för att göra ett antal fiktiva BAT-värderingar inom relevanta system. Det huvudsakliga syftet med dessa exempel var att identifiera viktiga delsteg och problemområden som guidelinen måste behandla. Denna process resulterade i de två exemplen som kan hittas i appendix XX. Vi har försökt förankra dessa fiktiva BAT-värderingar i verkligheten så gott som möjligt genom att ta in data från riktiga leverantörer.

Man dock ändå ifrågasätta att en stor del av metodiken är uppbyggd kring exempel eftersom det finns en osäkerhet kring hur väl dessa kan anses representera verkligheten. För att kvalitetssäkra de rekommendationer som ges har därför intervjuerna av BAT-experter varit betydelsefulla då de i stort har bekräftat den föreslagna metodiken. Den guideline vi föreslår ska dock inte ses som ett slutgiltigt dokument utan ska behandlas som ett levande dokument som kan uppdateras och modifieras av de personer som använder den.

En viktig del av frågeställningen inför det här examensarbetet gällde hur vi skulle tolka den definition av BAT som ges i IPPC-direktivet. Det var svårt att hitta litteratur angående BAT-begreppet och hur detta implementerades. Vi fann en del utförda BAT-värderingar men inga vetenskapliga artiklar som behandlade problematiken med begreppet eller hur man metodiskt genomför en BAT-värdering.

Detta gjorde att vi önskade undersöka hur BAT-begreppet idag tolkas och används i olje- och gasbranschen. Generellt bekräftade de intervjuer vi genomförde den tolkningen vi tidigare gjort av hur BAT ska definieras och hur en sådan värdering ska genomföras. Intervjuerna gav oss dessutom exempel på hur vissa av delstegen i BAT-processen kan göras.

De artiklar vi läste och de diskussioner vi hade i uppstartsfasen resulterade i att vi till en början koncentrerade oss på de ekonomiska aspekterna av BAT eftersom dessa lämnade stort utrymme för tolkning. Efter ytterligare diskussioner med våra handledare och efter att ha studerat IPPC-direktivets referensdokument ECM kom vi till insikten att BAT inte är tänkt att användas för djupare ekonomiska analyser. Eftersom BAT är framtaget som ett verktyg för att minska miljöpåverkan är det på miljö, dvs. Best-delen av begreppet, fokus bör ligga i BAT-värderingar.

Definitionen i IPPC som kan översättas ”bäst för miljön som helhet” lämnar vid en första anblick inte mycket tvivel om vad som menas. Vid närmare eftertanke inses dock snart att detta inte är så enkelt som det låter när det kommer till att jämföra tekniker och deras miljöprestanda. Att jämföra olika alternativs miljöpåverkan försvåras av att detta är starkt beroende av hur systemgränserna definieras. Hur bedömer man egentligen var en tekniks miljöpåverkan slutar? Detta är ett klassiskt problem i LCA-sammanhang och det är av yttersta vikt att avgränsningarna i studien väljs transparent. Dessutom bör den som utför studien hela tiden utvärdera hur resultatet påverkas av olika avgränsningar.

Eftersom två olika tekniker alltid kommer påverka miljön på olika sätt kommer man förr eller senare tvingas prioritera miljöeffekter relativt varandra. Vi har tidigare nämnt problematiken som ofta förekommer i oljebranschen där reducerade utsläpp av olja kan leda till en ökad energianvändning och därmed ökade utsläpp till luft. Man hamnar då i en situation där utsläpp av t.ex. CO_2 och NO_x till atmosfären ska vägas mot utsläpp av toxiska ämnen i hav. Det finns idag ingen vetenskapligt erkänd kvantitativ metod att göra en sådan värdering på. I praktiken måste dock denna avvägning ändå göras för att bestämma vilken teknik som ska väljas.

Den internationellt erkända metoden för att bedöma miljöpåverkan som går längst i jämförande studier är LCA-metodiken baserad på ISO 14040. Att denna ska ligga till grund för miljöbedömningar också i BAT-värderingar samt i den föreslagna metodiken känns därför naturligt. I LCA-metodiken understryks transparens och tydliga motiveringar för att skänka trovärdighet åt de bedömningar och val som görs och detta har vi framhållit genom vår framtagna metodik. ISO 14040 poängterar i den senaste versionen att kvantitativa viktningar baserade på förutbestämda beräkningsmetoder inte bör göras utan att tydligt kvalitativa bedömningar är att föredra. Vad som menas med detta är att man inte kan ta en redan gjord bedömning av vilken miljöeffekt som ska prioriteras och applicera den på sin egen situation. Istället bör individuella bedömningar göras utifrån rådande förutsättningar för att välja vilken miljöeffekt som ska prioriteras, vilket är det tillvägagångssätt som vi rekommenderat i guidelinen. De intervjuer vi genomförde bekräftade detta synsätt då ingen av de fyra intressenterna använde sig av kvantitativa och förutbestämda viktningsmetoder.

Så som ”Available” definieras i IPPC-direktivet lämnas stort utrymme för tolkning, både vad gäller ekonomisk och teknisk tillgänglighet. Som tidigare nämndes koncentrerade vi oss i början mycket på definitionen av ekonomisk tillgänglighet och hur denna ska bedömas. Vi försökte att i generella termer definiera vad som är ekonomiskt tillgängligt genom att monetärisera externa kostnader, dvs. sätta ett pris på miljöpåverkan. Utifrån detta försökte vi sedan genom en samhällsekonomisk kalkyl bestämma hur ekonomisk tillgänglighet bör bestämmas. Vi insåg snart att de data som krävs för att göra dessa analyser inte finns och är ytterst svåra att uppskatta på ett trovärdigt sätt. Även om dessa hade funnits att tillgå och analysen kunnat genomföras med ett rimligt resultat hade detta varit svårt att tolka och använda för det tänkta syftet. Analysen visar vad som är samhällsekonomiskt hållbart men frågan skulle kvarstå hur näringslivet (t.ex. ett oljeföretag) ska ta hänsyn till externa kostnader i sitt beslutsfattande. Sådana djupare analyser bör göras på en överordnad, branschnivå.

I en diskussion om vilka kostnader en viss bransch kan bära bör olje- och gasbranschen kunna tåla en relativt hög grad av ökade kostnader. Detta kan försvaras med att dess produkter, gas och olja, visat sig ha en näst intill obefintlig priselasticitet. Ökade kostnader i en bransch måste dock införas på global basis eftersom produkterna handlas på världsmarknaden. Skulle skattenivåerna för, t.ex. CO_2 ökas kraftigt i Norge skulle detta resultera i att oljebolagen flyttar sin verksamhet och miljöpåverkan utomlands. Vilka kostnader förknippade med miljöåtgärder som kan accepteras skiljer sig från företag till företag och att generalisera bedömningen av ekonomiskt tillgänglighet med en ekonomisk modell blir därför svårt.

Eftersom BAT-värderingar i huvudsak är ett verktyg för att bedöma miljöprestanda bör den ekonomiska analysen endast göras på en översiktlig nivå. I den metod som vi rekommenderar i metodiken kommer den ekonomiska analysen in i ett senare skede av värderingen då det miljöbästa alternativet är definierat. Den ekonomiska bedömningen ska då endast svara på om alternativet är ekonomiskt tillgängligt eller inte. I den föreslagna metodiken fokuserar vi på kostnadseffektivitet för att genomföra den ekonomiska analysen. Kostnadseffektiviteten kan på olika sätt relateras till historiska åtgärder eller referenspriser, t.ex. miljöskatter, för att bedöma dess tillgänglighet. Liksom i bedömningen av miljöprestanda är det viktigt att poängtera att den ekonomiska analysen görs individuellt utifrån gällande förutsättningar.

Vad gäller den andra delen av begreppet ”Available” – teknisk tillgänglighet har det visat sig att oljebranschen generellt är mycket konservativ gällande införandet av ny teknik. Det kan diskuteras varför det är så. Efter att ha studerat branschen under 6 månader anser vi dock att en stor del av denna inställning beror av dess höga krav på driftsäkerhet i de tekniska system som används offshore. Detta beror i sin tur på de höga kostnader och säkerhets- och miljörisker som kan förknippas med ett okontrollerat driftstopp. DNV har i anslutning till detta examensarbete uttryckt sin vilja att generellt i branschen och särskilt i den framtagna metodiken främja införandet av ny teknik. För att sammanföra dessa två skilda uppfattningar anser vi att DNV:s roll som riskhanteringsexpert och särskilt den del av deras verksamhet som kallas Technology Qualification (TQ) är rätt väg att gå. I TQ-processen analyseras det tekniska systemet och riskerna i varje enskild komponent synliggörs. Om riskerna med en ny teknik hanteras på det här sättet är det lättare för ett företag att väga potentiella värden med den nya tekniken mot den faktiska riskbild som finns. Vår uppfattning är att denna process måste till för att ny teknik ska införas då beslut om teknikinförande idag ofta tas baserat på företagens riskperception som baseras på en attityd och i många fall okunskap gentemot ny teknik. DNV har därför en viktig roll att spela när man certifierar ny teknik i TQ-processen. Denna analys är dock långt mer komplex och tidskrävande än vad som kan genomföras i en BAT-värdering. Vi har istället valt att i guidelinen rekommendera att en sådan analys eller motsvarande genomförts för att tekniken ska anses som tekniskt tillgänglig. Den tekniska bedömningen som vi rekommenderar i metodiken ska på samma vis som den ekonomiska analysen endast bedöma om det miljöbästa alternativet är tekniskt tillgängligt eller inte. Vi anser att denna analys ska göras översiktligt, kvalitativt och ”case-by-case”. Därför fann vi det svårt att sätta upp absoluta riktlinjer för hur detta ska genomföras. Detta försvårades ytterligare av vår begränsade erfarenhet av dessa bedömningar och de verktyg som kan tänkas användas.

Utifrån det sätt vi valt att tolka BAT-begreppet och behandlat det i metodiken kan ett antal begränsningar med denna identifieras. Att följa metodiken till punkt och pricka är en mycket tidskrävande process och i mindre omfattande BAT-värderingar är det inte rimligt att tro att den tiden finns. I dessa fall är det vikigt att prioritera de centrala modulerna i metodiken: att identifiera betydande miljöpåverkan för att sedan kunna jämföra teknikerna. Syftet med en BAT-värdering är att definiera vad som är den bästa tillgängliga tekniken. Kan det göras i ett tidigt skede är det inte nödvändigt att gå igenom alla moduler i metodiken. Samtliga moduler finns på plats för att kunna hantera så många tänkbara situationer som möjligt. Om BAT-värderingen förenklas på något sätt är det viktigt att upprätthålla transparensen och att motivera de val som görs.

För att bedöma miljöpåverkan av ett komplicerat tekniskt system krävs givetvis en god förståelse för hur dessa system fungerar. Det kan därför visa sig svårt att göra bedömningar av ett system som man aldrig tidigare stött på. Det kan även vara svårt att identifiera vilka system som ska inkluderas i BAT-värderingen när man inte har en bakgrundskunskap inom området. För att inte missa att inkludera tänkbara tekniker, och speciellt ny teknik, rekommenderar vi att den som utför värderingen tar kontakt med experter inom området för att kunna göra en rättvis värdering av systemet. Eftersom metodiken är tänkt att användas av DNV:s personal borde detta inte vara ett problem då DNV är ett globalt och tvärvetenskapligt företag som täcker stora kompetensområden.

Vi har tidigare nämnt att bedömningen av miljöpåverkan är det viktigaste steget i metodiken. Enligt vår erfarenhet är det svårt att identifiera de miljöeffektkategorier som ska tas med för utvärdering i tolkningsmodulen där de olika alternativen jämförs. De kategorier som tas med ska vara de som har störst miljöpåverkan. Såväl att bedöma detta som att ge riktlinjer för hur detta ska göras är mycket svårt. Ännu en gång är vår erfarenhet att detta måste göras kvalitativt, case-by-case.

Slutligen kan det diskuteras vilken funktion BAT som begrepp och arbetssätt fyller som miljöverktyg. Eftersom definitionen ger stort utrymme för tolkning är dess implementering i värderingar där BAT ska definieras helt utelämnat till hur den som genomför värderingen tolkar begreppet. Kunskapsnivån och intentionen hos den som utför värderingen kommer troligtvis prägla utgången av den. Som situationen ser ut i Norge idag kommer den kontrollerande myndigheten, Klif, ofta in i ett för sent skede av BAT-processen. Många system är då redan valda och företaget har låst sig till vissa tekniker genom leverantörskontrakt och chansen att påverka teknikval är därmed begränsad. Denna problematik försvåras ytterligare av begreppets benämning – Best Available Techniques – eftersom alla har en uppfattning om vad som är bäst. Denna uppfattning är subjektiv och kan, beroende på vem som tillfrågas, präglas av ekonomiska, tekniska, miljömässiga eller övriga aspekter. Många finner det därför inte nödvändigt att söka upp definitionen och innebörden av begreppet så som den ges i IPPC-direktivet.

Frågan är också om BAT idag fungerar som det var tänkt och om det leder till reducerad miljöpåverkan. Att spåra förändringar till BAT-direktivet är svårt eftersom det inte är lika enkelt att se t.ex. reducerade utsläpp som när ett nytt utsläppskrav eller ett ekonomiskt styrmedel införs. Om ett förbud av en toxisk substans införs kommer detta med största sannolikhet att resultera i en kraftfull minskning på kort tid. När man istället använder sig av BAT-värderingar, där ekonomisk och teknisk tillgänglighet vägs in, för att minska utsläppen av en toxisk substans är det inte säkert eller ens troligt att detta ger samma resultat. Detta eftersom det är upp till varje värdering att bestämma vad som är ”tillgängligt” och att definiera detta är som diskuterats ytterst subjektivt. Hårdrar man denna diskussion kan man fråga sig vad BAT tillför som miljöverktyg i förhållande till ekonomiska och administrativa styrmedel? Kanske är BAT endast ett sätt för beslutsfattare att flytta över ansvaret för miljöförbättrande åtgärder från den politiska arenan till näringslivet. Liksom med andra miljöverktyg med vagt formulerade mål som grundar sig på ”frihet under ansvar”, t.ex. miljöledningssystem, bygger effektiviteten i BAT som miljöverktyg på välviljan hos de som använder sig av och tar beslut utifrån dessa värderingar. Eftersom en strikt kontroll av BAT-värderingar frångår den självreglerande princip som genomsyrar direktivet skulle detta inte vara att föredra. Om BAT, som det är definierat idag, ska få det genomslag som önskas krävs att företagen sätter ett långt större värde på miljö än vad de gör idag. Detta skulle kunna åstadkommas genom fler och striktare ekonomiska styrmedel eller som ett resultat av allmänheten ställer allt högre krav på företagens miljöarbete.

14 Slutsats

Att bygga upp en metodik för något som vi aldrig tidigare hade genomfört praktiskt visade sig vara en utmaning. Detta försvårades ytterligare av att BAT-värderingar till stor del är kvalitativa och görs från fall till fall, vilket är oundvikligt då det ligger i begreppets vaga natur. Med dessa förutsättningar är det mycket vanskligt att utveckla en metodik för BAT-värderingar.

BAT tolkas i den framtagna metodiken som ett verktyg för att jämföra miljöprestanda hos olika tekniker. Syftet med detta är att finna den, ur miljösynpunkt, bästa tekniken. Enligt BAT-begreppets innebörd ska även ekonomiska och tekniska aspekter bedömas. I metodiken föreslår vi att man endast översiktligt kontrollerar huruvida den miljöbästa tekniken är ekonomiskt och tekniskt tillgänglig eller inte.

Det är erkänt svårt att väga olika typer av miljöpåverkan mot varandra. Vi har i metodiken hanterat detta genom att applicera vissa delar av LCA-strukturen eftersom detta är den mest accepterade metoden för att bedöma och jämföra miljöpåverkan.

Som BAT-begreppet är definierat idag är det inte säkert att det faktiskt leder till minskad miljöpåverkan. Effektiviteten i verktygets praktiska användning bygger i stort på kunskap om begreppet samt inställningen i miljöfrågor hos de som utför och tar beslut utifrån BAT-värderingen. Idag finns troligtivs verktyg som leder till såväl mätbar som effektivare miljöförbättran.

15 Referenser

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Appendix A Example BAT assessment – Energy production

Table of contents

1 Introduction

The purpose of this Best Available Technique (BAT) assessment is to exemplify the DNV guideline on BAT and to show how such an evaluation may be built up in a concept phase of a development project. Therefore, the intended platform and its energy production system will be described in very general terms. This can be motivated by not yet having access to details on the project.

Moreover, the original intention of this example assessment was to focus on the Environmental Impact Assessment (EA) and the interpretation phases. More specifically we aim to exemplify the classification, characterization and ranking processes more closely in this example. This was done in order to develop this part in the DNV guideline.

1.1 Method

Two environmental impact assessments have been most useful in the construction of this assessment: the environmental impact assessment for Gjøa from Statoil and the environmental impact assessment for Goliat from Eni Norge. While located in different parts of the Norwegian continental shelf with vastly different ecological conditions and regulation, they are similar in their distance from shore, depth and chosen concepts (2006, 2008).

1.2 Definitions

Assessor	The person(s) doing the assessment on Best Available Techniques
Available techniques	Developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced in the Member State in question, as long as they are reasonably accessible to the operator (2008/1/EC)
Best	Most effective in achieving a high general level of protection of the environment as a whole (2008/1/EC)
CO_2	Carbon dioxide
DNV guideline (on BAT)	Guideline on BAT for implementation on oil and gas platforms written by the autors
Environmental Assessment (EA)	The process of categorising and characterising the data gathered in the DI
Environmental	The effect on the environment caused by the

Impact Category (EIC)	emission/discharge of a certain stressor or sustainability issue or environmental risk
Environmental Impact Assessment (EIA)	Document that must be handed in to and be approved by authorities for all projects that may have a significant impact on the environment. This includes all offshore installation projects.
Interpretation	The process of analyzing the information in the EA
Data Inventory	The process of gathering information on a certain technique
NO_x	Nitrogen oxides, refers to a mixture of NO and NO_2
Platform	The physical installation used for oil and gas production offshore
Rig	See platform
SO_x	Sulphur oxides, refers to one or more of various sulphur oxide compounds, mainly SO_2
Stressor	An emission or discharge, which leads to one or several environmental impacts
Techniques	May refer to both a technology and the way in which the installation is designed, built, maintained, operated and decommissioned (2008/1/EC)
Technology	Tools, machinery or a system of machinery created to fulfil a specific function

1.3 Abbreviations

AP	Acidification Potential
BAT	Best Available Techniques
CO_2	Carbon dioxide
DI	Data Inventory
DNV	Det Norske Veritas
ECM	IPPC Reference Document on Economics and Cross-Media Effects
EA	Environmental Assessment
EIC	Environmental Impact Category
EP	Eutrophication Potential
FEED	Front End Engineering and Design
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control

LCA	Life Cycle Analysis
nmVOC	non-methane Volatile Organic Compounds
NO_x	Nitrous Oxides
PM	Particulate Matter
POCP	Photochemical Ozone Creation Potential
SO_x	Sulphur Oxides

2 Scope & boundary definition

2.1 Site specific conditions

This BAT assessment shall evaluate techniques for energy production on the Gjøa platform located in the North Sea. Gjøa is located on the Norwegian continental shelf approximately 45 km from land at a water depth of 360 m.

2.2 Theoretical definitions

On an oil rig energy is needed in the form of power and heat to serve the production and processes on-site. Power is consumed in the operation of an oil rig in pumps used for extracting oil from the wells, pumps and compressors used in oil and gas export, sea water lift pumps, ballast pumps, pumps used in the injection of produced water and in the living quarters. Heat is needed in e.g. the separation process, where oil, gas and produced water are separated from each other. Treatment of bilge and produced water may also prove a major heat consumer (Haukebø 2010).

Energy production causes emissions to air of different stressors. The potential impacts from these are mainly global warming, acidification, eutrophication, human toxicity and photochemical ozone creation potential. These will not be described in any detail here as the reader is assumed to be well-acquainted with common environmental impacts.

2.2.1 Significant environmental impacts

Emissions to air from energy production are the most significant environmental aspect from the operation of oil and gas platforms. Of these CO_2 and NO_x are the most significant stressors (Kirkeng 2010, Sandgrind 2010, Jonson 2010).

2.3 Constraints

2.3.1 Regulatory constraints

A. Taxes/costs

CO_2 cost: appr 400 NOK/ ton CO_2 emitted (combined CO_2 tax and CO_2 quota cost for the offshore industry) (Sandgrind 2010).
NO_x cost: 15 NOK/kg NO_x (Sandgrind 2010)

B. NORSOK standard S-003

The following should be considered in order to increase efficiency of energy production:

- Gas turbine cycle enhancement
- Integrated or shared power generation with other installations, as well as the possibility to provide energy from shore
- Selection of optimum number, size and make of turbines according to power demand profile

- Turbines should be of low-NOx type: <25 ppmv

2.3.2 Functional & capacity constraints

The function of the different concepts evaluated in this assessment is to provide the platform with electrical and heat energy. The systems evaluated should comply with the capacity requirements during the whole lifetime of the operation of the platform. To determine the demand for power and heat during the project lifetime the expected loads specified in the environmental impact assesment for Gjøa has been used. This estimation results in a total expected energy demand of **4,74 TWh power** and **2,83 TWh heat** during the lifetime of the platform.

The Gjøa platform will have a maximum process heat demand of 48 MW (Statoil 2006). The maximum power demand will be 39 MW excluding the export gas compressor. The export gas compressor will have an energy demand of 26 MW, which can either be supplied by an electric engine or a turbine with a mechanical energy output (Statoil 2006).

These constraints result in five alternatives for the power generation

1. Full electrification from shore

Transmission capacity of 113 MW_{el} (65 + 48 MW) is needed.

2. Electrification from shore

Transmission capacity of 65 MW_{el} is needed
Heat production offshore of 48 MW needed

3. Semi-electrification from shore

Transmission capacity of 39 MW_{el} is needed
Offshore production capacity of 26 MW power, and 48 MW heat needed

4. Offshore energy production with simple gas turbine cycle fitted with waste heat recovery

Offshore production capacity of 113 MW, of which 48 MW heat

5. Offshore energy production with combined gas turbine cycle fitted with waste heat recovery

Offshore production capacity of 113 MW, of which 48 MW heat.

2.3.3 System boundaries

The studied system in this assessment is energy production, which can be said to be an active system meaning that its largest environmental impact occurs in its use phase. In general, it will throughout its operation lead to emissions of stressors. Therefore, the maintenance and end-of-life will potentially hold less significance. However, because some of the installations used for energy production are of significant size and consume large amounts of raw material the construction will also be considered.

The nature of the system studied in this assessment also makes it difficult to define system boundaries as the conditions vary according to each energy production technology. Two principal sets of boundaries have therefore been used, one applied for onshore energy production techniques, and the other for offshore techniques.

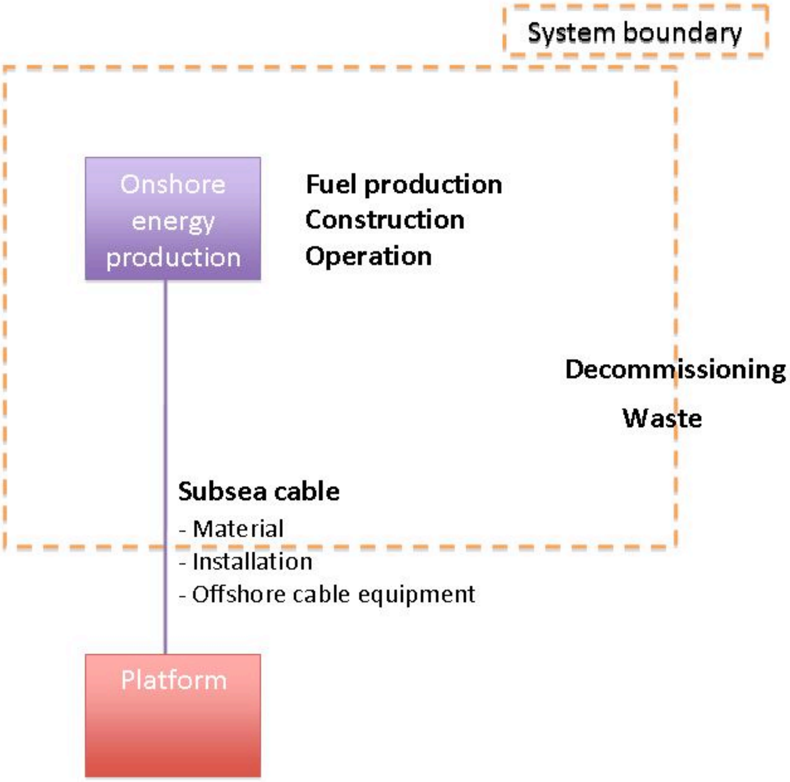

Figure 10 System boundary for onshore energy production.

In Figure 10 the system boundary for the onshore energy production alternatives are shown. This is applicable on all alternatives that use power from shore. Fuel production, construction and operation of the power plants are included in all energy production technologies evaluated. Decommissioning is included in all technologies but hydropower. Emissions from waste disposal are included in coal CHP power and coal power. The emissions caused by the material use in the subsea cable are included in the study but emissions from the installation of the cable and other equipment onshore and the platform (e.g. inverters) are not included. These assumptions are listed in the DI.

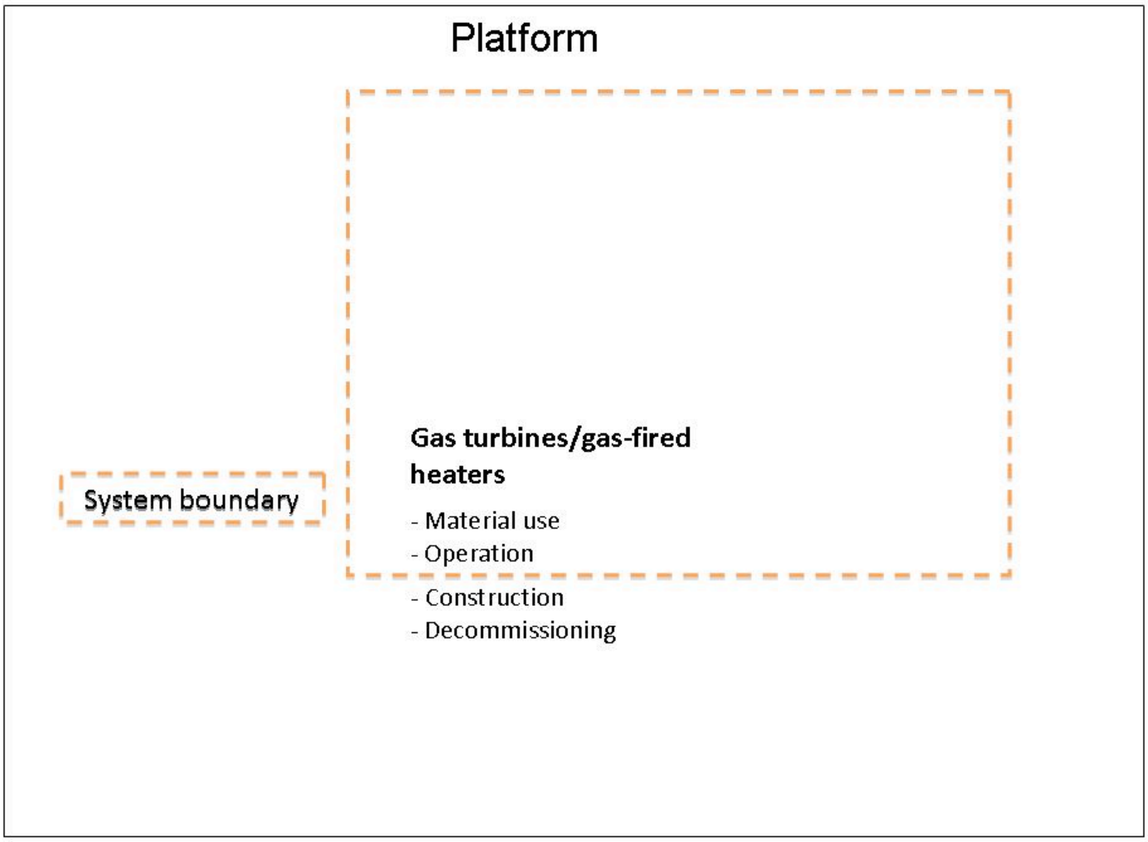

Figure 11 System boundary for offshore energy production.

For offshore energy production the emissions caused by the operation of gas turbines/gas-fired heaters on the platform are included as can be seen in Figure 11. The material use in the turbines/heaters will also be included in this study. The emissions from the installation and decommissioning will not be included as these are assumed to be negligible compared to the operation of the turbines.

2.3.4 Functional unit

The functional unit hence the basis for comparison in the assesment is **useful energy production satisfying the total lifetime expected energy demand of 4.74 TWh power and 2,83 TWh heat**. This definition will from now on be refered to as the functional unit (FU) and all environmental impact listed when comparing the alternatives will be presented as environmental impact/FU.

3 Data Inventory (DI)

3.1 Technique screening

The different technologies for energy production considered here are all conventional and no detailed description of them will be provided. As this is a BAT assessment performed on a conceptual level the comparison will be done on an equally general level. Therefore, different suppliers will not be studied. Instead data representative of the individual alternatives will be collected.

3.1.1 Offshore gas turbines simple cycle

The data for both the simple gas turbine cycle and the combined gas turbine cycle alternatives have been based on data attained from the gas turbine supplier Siemens Industrial Turbomachinery AB in Finspång, Sweden. The concepts have been dimensioned according to the maximum expected energy demand profiles for heat and power and expected weather conditions at the Gjøa platform. Regarding redundancy requirements and availability for the concepts, Göran Thellander's, Siemens, experience from similar installations offshore has been applied together with from the expertise of Kim Kristensen, PARAT (Tjellander, Kristensen 2010).

The proposed simple gas turbine cycle solution consists of four SCC-600 units made up of a SGT-600 gas turbine fitted with a waste heat recovery unit with complementary gas firing. Each unit is dimensioned to deliver 33 % of the maximum electric load, and in normal operation three of the gas turbines are in use and one is at standby. If one of the gas turbines fails the fourth turbine can be started in approximately 20 minutes. During this start up time the system is only able to satisfy approximately 70 % of the maximum expected electric load. This redundancy setup is assumed to be sufficient enough for operation of the platform.

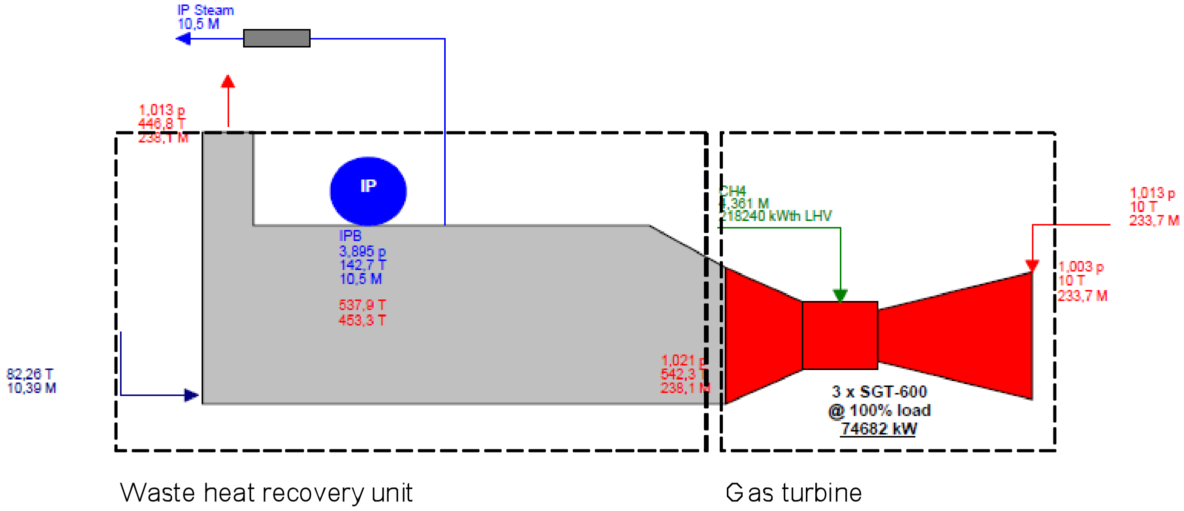

Figure 12 Schematic - simple gas turbine cycle.

A problem when estimating emissions from gas turbine concepts is that their efficiency varies with the load. For the simple gas turbine concept two heat balance calculations have been performed by Siemens, first running turbines at 100 % load matched against the maximum expected power demand of 65 MW. Secondly at 70 % load matched against the maximum heat demand of 48 MW. The results from the two runs calculated by Simens have then been used to linearly extrapolate how the efficiency varies with load.

To calculate the emissions from the gas turbine the following assumptions have been made.

- The fuel used is 100 % methane with lower heating value of 13,9 kWh/kg.
- To calculate CO_2-emissons all carbon in the fuel is assumed to be completely oxidized to CO_2.
- Emissions of NO_x, CO, and PM are not affected by varying load other than indirectly through decreased efficiency.
- The concentration ratio between emission species in the exhaust gases is constant over the project lifetime.
- To maintain demanded maximum power output throughout the project lifetime the turbines are dimensioned with a safety margin of 10 MW. In calculations this is expressed as a decrease in efficiency evenly distributed under the project lifetime.
- The average air temperature was assumed to be 10 ° C.
- The average water temperature was assumed to be 5 ° C.
- To satisfy the heat demand, steam at 160 ° C and 3,5 bar is produced in the waste heat recovery units.

Emission calculations are also based on the following guaranteed emission levels for the SGT-600 gas turbines given at 100 % load and 15 % O_2 content in dry flue gases.

Table 3 Emission values of simple gas turbine

NOx (ppmvd)	CO (ppmvd)	PM (mg/Nm^3)
25	35	5

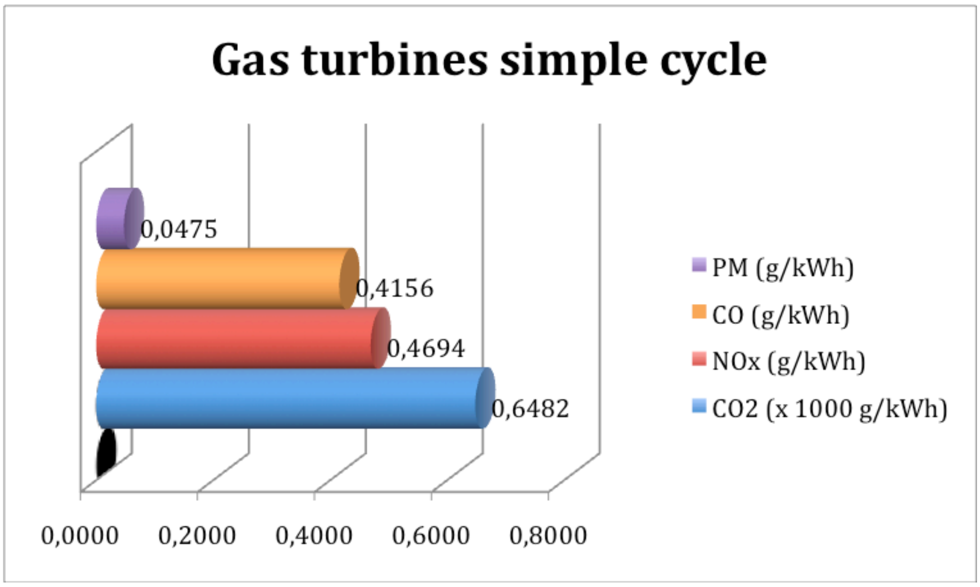

Figure 13 Emissions from the life cycle of gas turbines.

3.1.2 Offshore gas turbines combined cycle

The proposed combined gas turbine cycle concept consists of 3 SCC-700 units connected to a steam turbine. The SCC-700 units are made up of three SGT-700 gas turbines each with waste heat recovery with complementary gas firing. In total, the concept thus consists of four production units. In normal operation the steam turbine and two of the gas turbines together provide a power output of maximum 65 MW. The third gas turbine is normally in standby mode and if one of the other gas turbines fails it can be started in approximately 20 minutes. During this start up time the system could only satisfy 50-70 % of the maximum expected electric load. This redundancy setup is assumed to be sufficient enough for the operation of the platform.

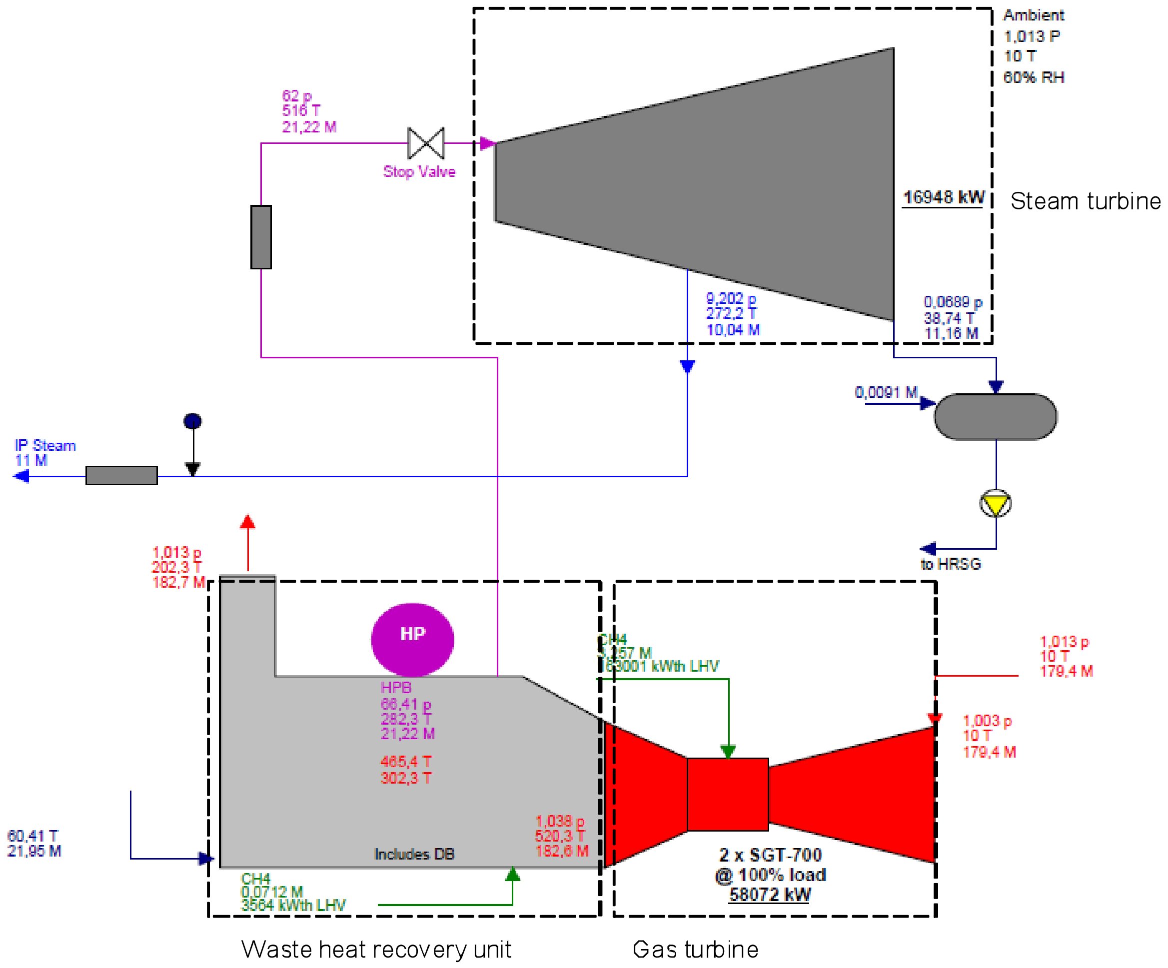

Figure 14 Schematic - combined cycle gas turbines.

As for the simple cycle gas turbine concept Siemens has performed two heat balance calculations, one at 100 % load matching the maximum expected power demand, and another at 70 % load corresponding to the maximum expected heat demand. The two calculations have also been used in the same way as for the simple cycle to estimate how the efficiency varies with the load. The same assumptions as listed in the simple cycle concept have also been used in the combined cycle concept. Emission calculations are based on the following guaranteed emission levels for the SGT-700 gas turbine given at 100 % load and 15 % O_2 content in dry flue gases.

Table 4 emission values of combined gas turbine cycle

NOx (ppmvd)	CO (ppmvd)	PM (mg/Nm^3)
24	25	3

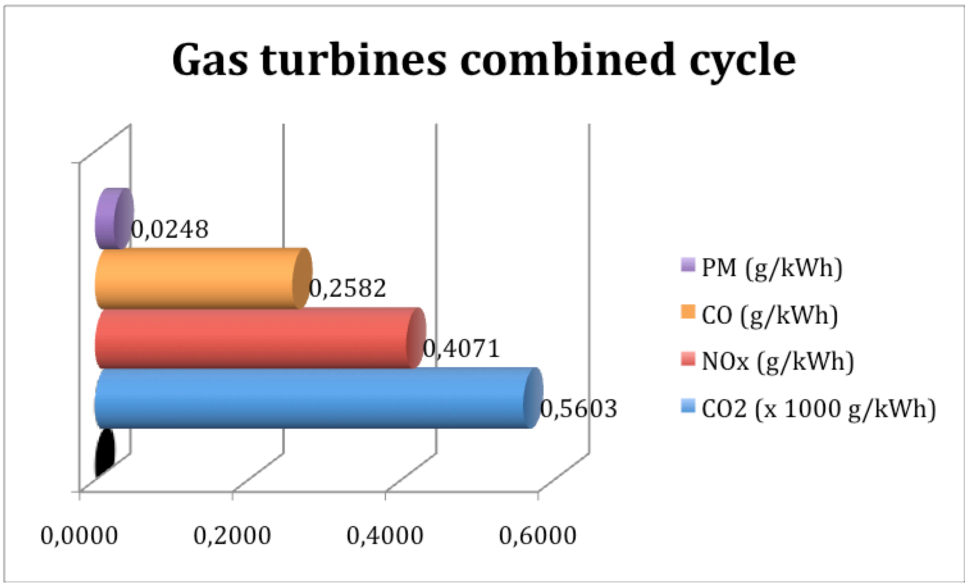

Figure 15 Life cycle emissions from combined cycle gas turbines.

3.1.3 Offshore gas-fired heaters

In order to estimate emissions from gas-fired heaters used in alternative 2 and 3 we contacted PARAT. In alternative 2 where the total expected heat demand is supplied by gas-fired heaters, PARAT suggests a concept of three boilers of 24 MW each. To satisfy the maximum demand of 48 MW two boilers are operated at 100 % load and one boiler is on standby as backup. According to PARAT the efficiency in the boilers is 91 % and is assumed to be unaffected by load variations under the project lifetime (Kristensen 2010).

Gas-fired heaters are also used in alternative 3 to top up the heat production not covered by the waste heat recovery unit of the export gas turbine. These heaters are assumed to have an efficiency of 91 % and as in alternative 2, three units are used, each one with a capacity of 50 % of the needed load. In normal operation two units run at 100 % load and one is on standby as back up.

For both alternative 2 and 3 the following assumptions apply when calculating the emissions caused.

- The fuel used is 100 % methane.
- The air inlet temperature is 0-50 ° C
- Dry flue gases for a 24 MW unit is constant at 9 Nm^3/s at 100 % load
- O_2 content in dry flue gases is 3%
- CO_2 content in dry flue gases is 10 %
- NO_x content in dry flue gases is maximum 70 ppm
- CO content in dry flue gases is maximum 50 ppm
- VOC content in dry flue gases is maximum 10 ppm
- PM content in dry flue gases is maximum 18 mg/Nm^3

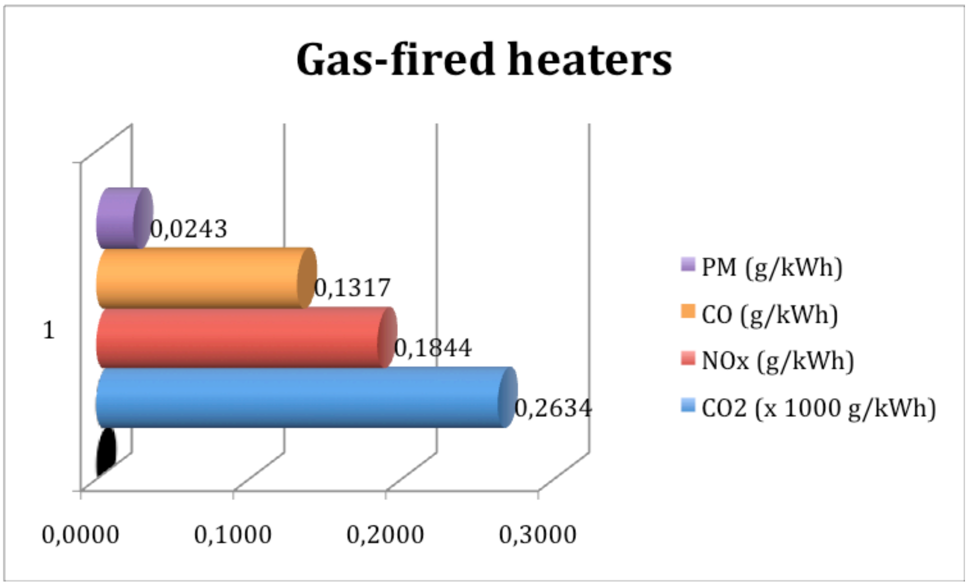

Figure 16 Life cycle emissions from gas-fired heaters.

3.1.4 Hydropower

4 power plants on the Lule river and 3 power plants on the Ume river in northern Sweden have been used in this DI. Both rivers have multi-year reservoirs. The assessments include resource use and emissions from construction, reinvestments and operation. The model does not include decommissioning because the reinvestments will create an outflow of installations functionally equal to newly constructed ones at the end of the life span. The life spans chosen are 60 years for machinery and 100 years for concrete constructions and dams (Vattenfall 2005).

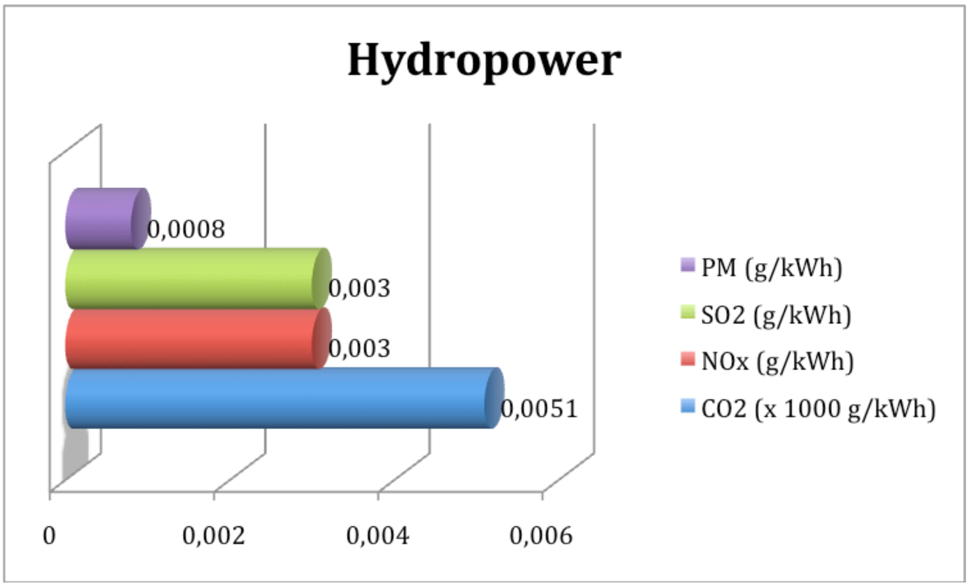

Figure 17 Emissions from the life cycle of hydropower (Vattenfall 2005).

3.1.5 Nuclear power

The DI data here presented is based on the three boiling-water reactors in Swedish Forsmark and three compressed-water reactors and one boiling-water reactor in Ringhals, also in Sweden. The Swedish nuclear power plants were constructed between 1965 and 1984. The assessments include resource use and emissions from mining of the uranium fuel, the construction and decommissioning of the power plants as well as the installations that deal with generated nuclear waste. The life span has been set to 40 years. The largest part of the environmental impact from nuclear power occurs in the fuel production (Vattenfall 2005).

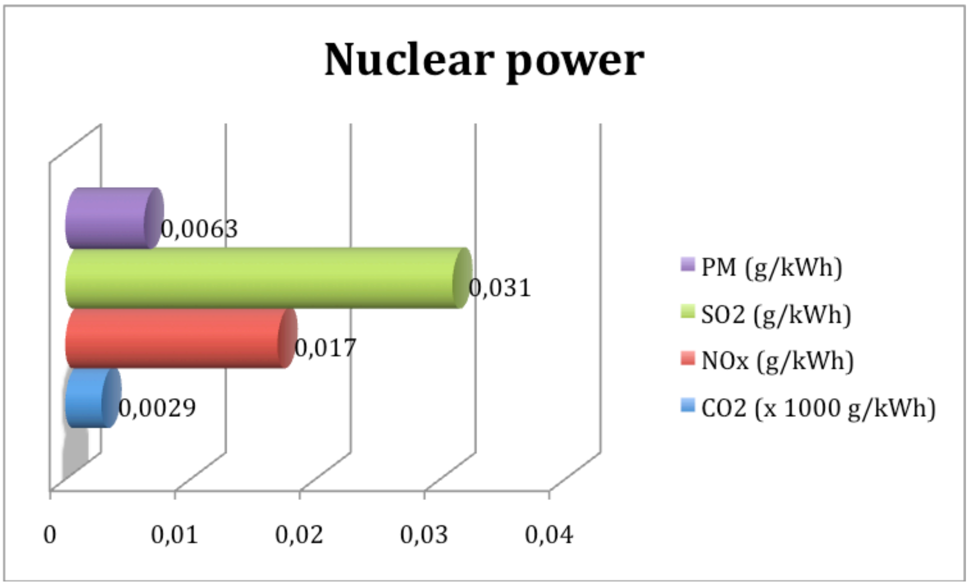

Figure 18 Emissions from the life cycle of nuclear power (Vattenfall 2005).

3.1.6 Wind power

The DI data for wind power is based on 11 plants with a capacity between 0.2 and 1.5 MW and whose wind exposure, manufacturer and sizes are representative of Vattenfall's generation. The life cycle includes construction of the plants, in which the major environmental impact occurs, and the operational phase, which includes travel, oil consumption and reinvestments. The technical life span is set to 25 years (Vattenfall 2005).

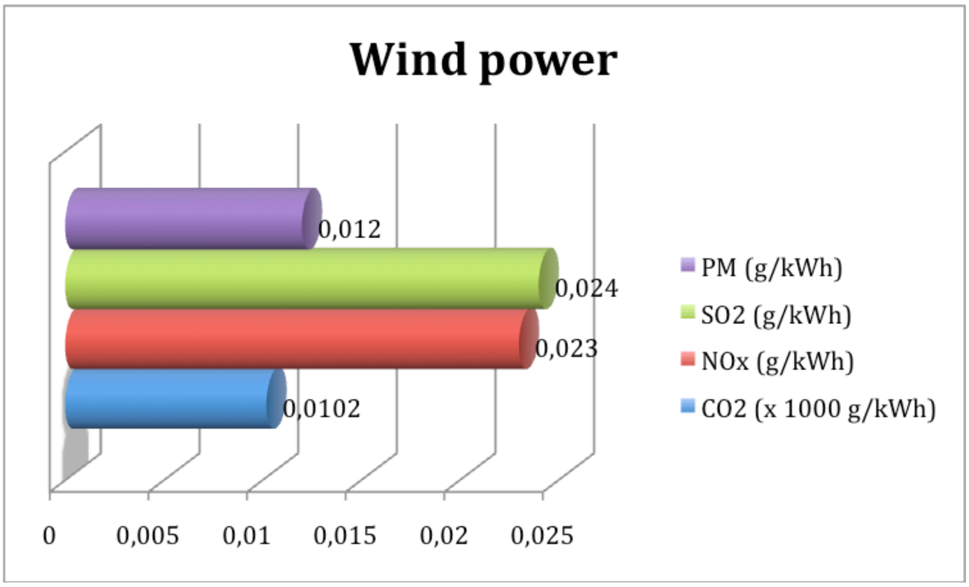

Figure 19 Emissions from the life cycle of wind power (Vattenfall 2005).

Wind power is a field of constant and rapid development. Especially the capacity of wind mills is constantly increasing and as of 2010 2 MW plants can be said to be standard. Higher-capacity wind power means that the environmental impact per generated kWh is reduced. Therefore, it is likely that the stated emissions are higher than the average today.

3.1.7 Natural gas combined cycle

The studied plant is a 900 MW_{el} natural gas-fuelled combined cycle plant with an assumed efficiency of 58%. The technical life span of the installation is set to 40 years (Vattenfall 2005).

Emissions include those caused from the extraction of gas from the North Sea, gas treatment at Kårstø on the Norwegian mainland, transportation in pipelines to Sweden and combustion in the power plant. The life cycle includes emissions to air and water, resource use and waste products generated during drilling and extraction of the natural gas, the construction of pipelines and gas storage as well as the construction and decommissioning of the power plant (Vattenfall 2005).

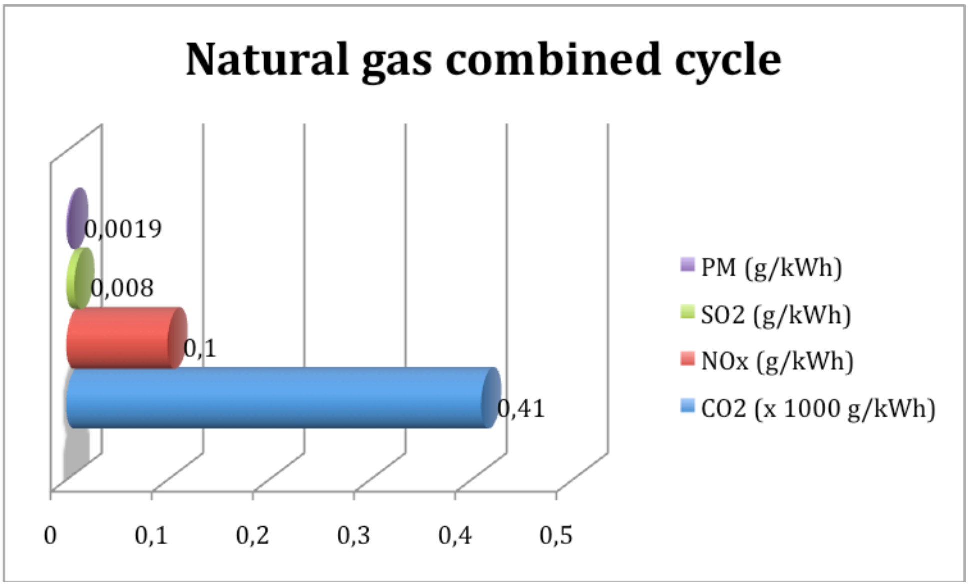

Figure 20 Emissions from the life cycle of natural gas combined cycle (Vattenfall 2005).

3.1.8 Coal-fired CHP

Co-generation of heat and power is a means of energy production where fuel, in this case coal, is combusted and the end products are both heat and power.

The life cycle has been based on two Swedish CHP plants that are designed to use several different fuels. The life cycle includes fuel production, combustion and ash disposal as well as construction, reinvestment and decommissioning of the power plants. Allocation of environmental impacts between heat and power has been done accordingly to the rules for environmental product declarations. Vattenfall mainly buys coal from Polish and Russian mines. The coal is transported by train, ship and truck to the power plant where it is ground up (Vattenfall 2005).

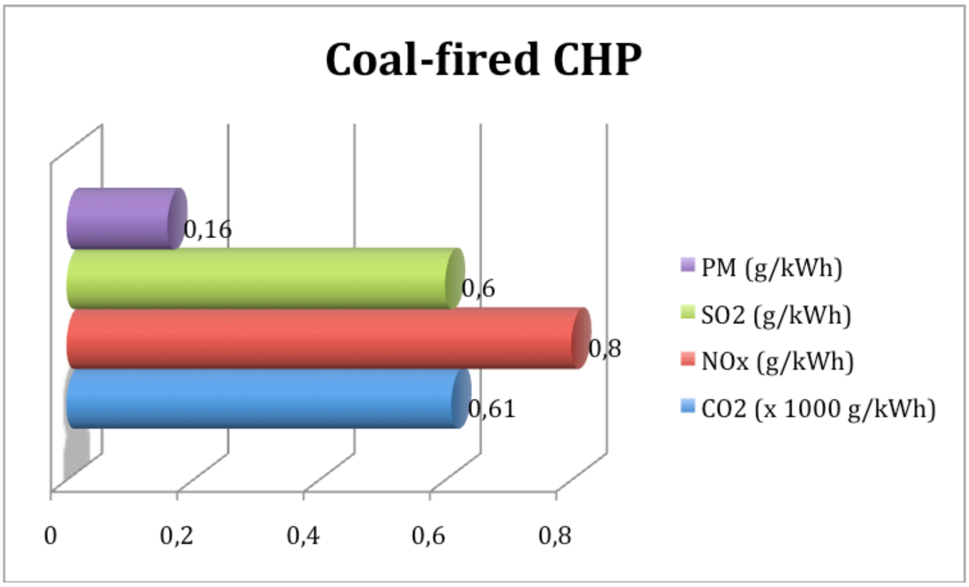

Figure 21 Emissions from the life cycle of coal-fired CHP (Vattenfall 2005).

3.1.9 Coal Power

The data for the construction, decommissioning and operation used in this DI is based on a LCA conducted in 1998 on a Danish coal power plant with a capacity of 385 MW. This is complemented by fuel data from the Swiss data base. The plant was designed to operate both as a condensing plant and as a CHP plant. When operating as a condensing power plant the efficiency is assumed to be 47% and excess heat is cooled off. The plant is of conventional type with boiler and steam cycles, equipped with electro-filter for cleaning of particulate matter, wet sulphur removal with chalk and nitrogen reduction with ammonia. The life cycle includes construction, reinvestments, decommissioning, mining, purification and refining of the fuel, fuel transportation and storage, combustion in the plant and treatment of the ash. The technical life span is set to 40 years (Vattenfall 2005).

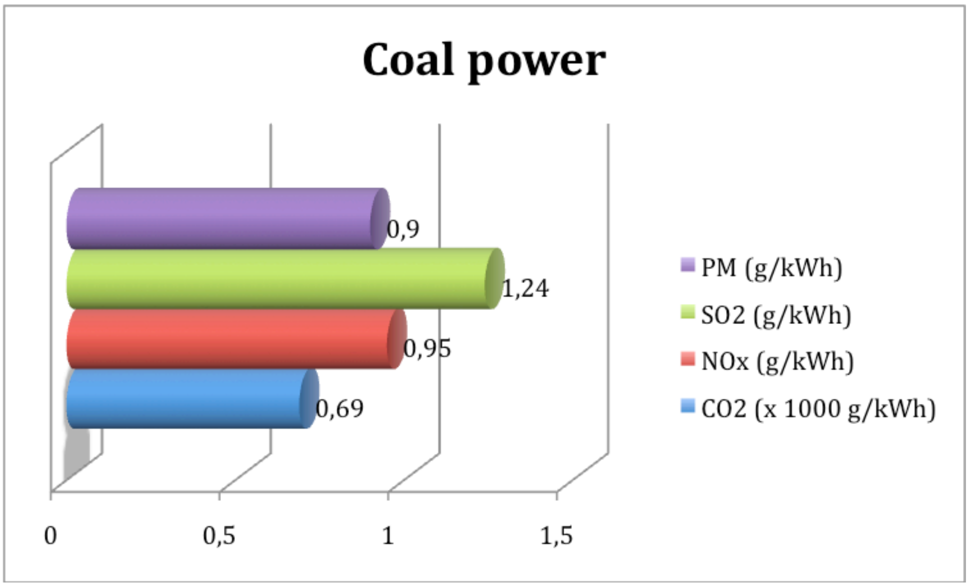

Figure 22 Emissions from the life cycle of coal power (Vattenfall 2005).

3.1.10 Cable

For the different electrification alternatives a cable from land will be needed. The emissions caused by the construction and installation of this cable are not included in the above inventory data and will have to be assessed separately.

It is assumed that the emissions from the installation of the cable itself are negligible compared to those that arise from the installation of the whole platform. All emissions are therefore assumed to be from the construction of the cable. The whole installation; dynamic and static cable, and connection will be approximated with a static cable. The cable is assumed to only consist of copper and lead. The density of the cable is assumed to be 60 kg/m cable and the length of the cable 45 km. It is assumed that 67% of the mass of the cable can be allocated to the lead and 33% to the copper (Röstlund 2010). Finally, it will be assumed that all three electrification alternatives can be accommodated by the same type of cable.

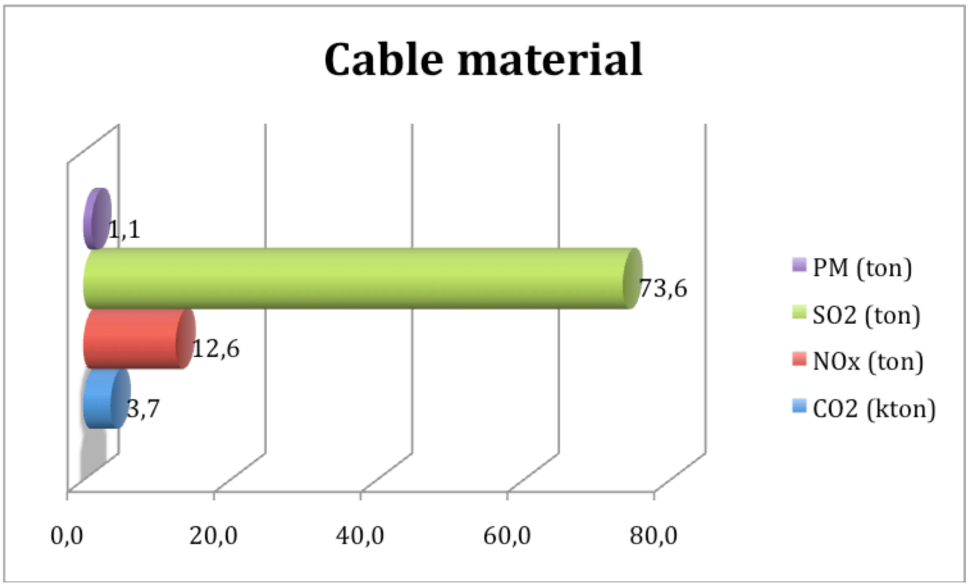

Figure 23 Emissions from life cycle of the cable material (Rydh et al. 2007, EU LCA Database 2010).

3.2 Cut-off

During the process of this assessment it was found that, in terms of mass, CO_2-emissions are generally some 1000 magnitudes larger than other stressors in energy production. Moreover, in some energy production technologies emissions of SO_2 and PM are insignificant compared to the emissions of CO_2 and NO_x. They are, however, significant for other technologies and have a potentially large environmental impact. For these reasons they were included in the assessment and no quantitative cut-off limit was defined. Stressors included in this assessment are: CO_2, NO_x, SO_2, PM. They were found to be most significant in terms of environmental impact and data for these were easily available from the Vattenfall LCA. For offshore energy production techniques emissions of CO were also included.

3.3 Data quality

The information in categories 3.1.1 and 3.1.2 above is based on rudimentary calculations that Siemens have done with their own turbines as an example. The data has been derived exclusively for the purpose of this assessment with the specific conditions and constraints as a general basis. They should, however, not be seen as representative for Siemens' products as the exact conditions and requirements were not available in this example (Tjellander 2010). The data should, nevertheless, have a high quality.

In category 3.1.3 data has been estimated from previous similar installations made offshore by PARAT for gas-fired heaters. These emission data has then been used in the assessment. As gas-fired heaters is a very mature technology and emission data is based on real measurements, the data quality can be said to be high (Kristensen 2010).

The information for categories 3.1.4 through 3.1.9 has been obtained from an extensive life cycle assessment done by Swedish power company Vattenfall in 2005. In this LCA they evaluate the power produced by their own plants in the Nordic countries. These include hydropower, nuclear power, wind power, CHP multi-fuel plants, natural gas combined cycle, coal-fired CHP and coal power (Vattenfall 2005). Vattenfall's production units are located in Sweden and Denmark and their hydropower plants and natural gas combined plant can be said to have been built under similar conditions as those built/planned in Norway. The data here presented are therefore seen as representative for the Nordic countries and the electricity sold on the common electricity market Nordpool.

3.4 Uncertainty

An analysis of the uncertainty in collected data has not been performed due to lack of time.

4 Environmental Assessment (EA)

4.1 Stressors

4.1.1 Classification

The seven themes for environmental impact discussed in the ECM have been considered and of these five Environmental Impact Categories (EICs) can be related to the emissions from the DI. The impact categories seen in Figure 24 will be used as base when comparing the various technologies for energy production: acidification, global warming, eutrophication, human toxicity and photochemical ozone creation potential.

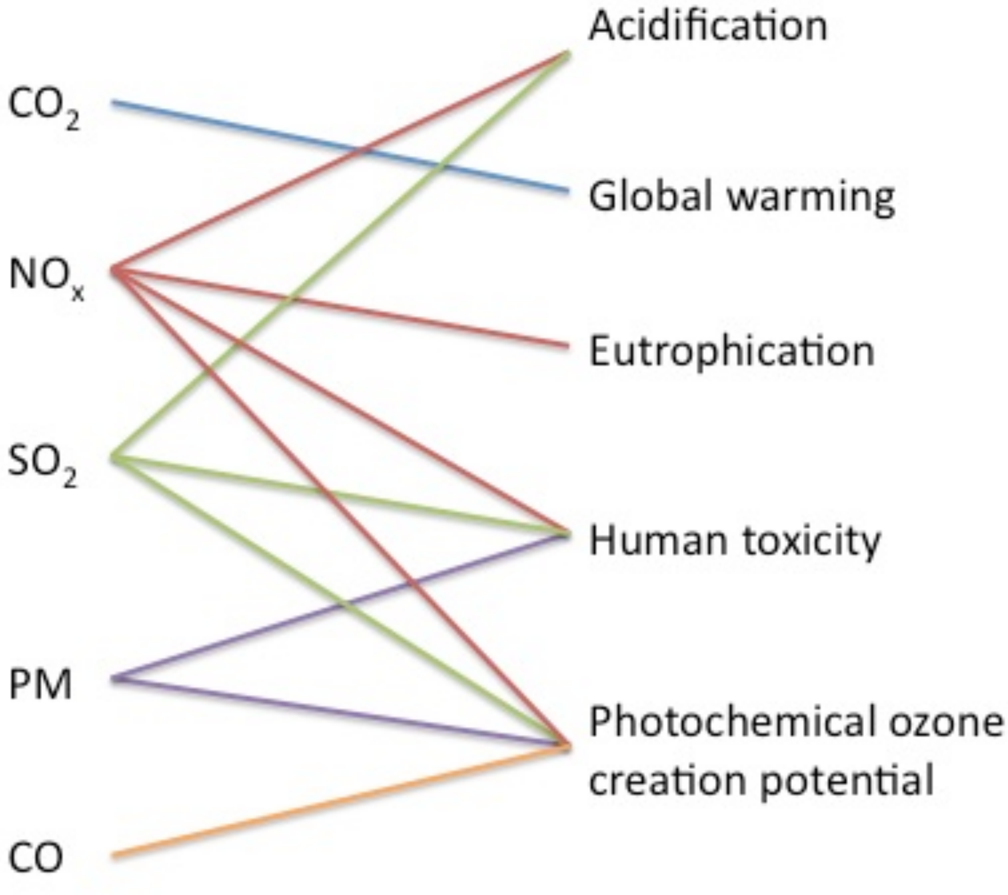

Figure 24 Classification into environmental impact categories.

As can be seen in Figure 24 CO_2 can only be related to global warming. NO_x, on the other hand, is related to all impact categories but global warming. SO_2 can be coupled with acidification, human toxicity and photochemical ozone creation potential. Particulate matter (PM) can be classified in the two categories human toxicity and photochemical ozone creation potential (ECM 2006).

Whether or not NO_x should be related to global warming is discussed in the latest IPCC report. However, the complex chemistry and short lifetime of NO_x make calculations of its GWP very uncertain. Due to the lack of agreement even on the sign of the global mean GWP among the different studies no such number was presented (IPCC 2007).

4.1.2 Characterization

The characterization factors in Table 5 have been attained from the ECM.

Table 5 Characterization factors for studied environmental impact categories (ECM 2006)

Species	***Acidification potential (g SO2 eq/g)***	***Global warming potential (g CO2 eq/g)***	***Eutrophication potential (g PO43-/g)***	***Human toxicity factor***	***Ph. chem. creation potential (g C2H4 eq/g)***
CO_2		1			
NO_x	0,5		0,13	N/A	-0.06 to 3,8
SO_2	1			N/A	0,048
PM				N/A	
CO				N/A	0,027

Where no mean characterization factor for NO_x was provided by the ECM this species has been approximated with NO_2 except in the case of photochemical ozone creation potential where the range (which includes the NO_2-range) for NO has been used. For human toxicity no applicable characterization factor to the stressors here presented was found. Moreover human toxicity is a very local issue that will not prove important for offshore energy production. Human toxicity is not a problem in this region (AirClim 2008).

For global warming, the 100 year time horizon has been used, as recommended by the IPCC (IPCC 2007).

4.1.3 Presentation of stressor EICs

The results from the EA so far shall be presented below for each of the five alternatives previously discussed. Of the five EICs shown in Figure 24 four will be evaluated used in this assessment. As previously mentioned human toxicity was found to be mainly a local issue with minor importance in the studied region and was dismissed as an EIC. A baseline case for the electricity mix will be created.

4.1.3.1 Baseline case

The environmental impact of the electrification alternatives will depend on what power generation technology is used. The power generation technologies used in Norway can be seen in Table 6.

Table 6 Electricity production in Norway 2007 (IEA 2010).

Coal	144	0,10%
Oil	27	0,02%
Gas	730	0,53%
Biomass	317	0,23%
Waste	126	0,09%
Hydro	135052	98,24%
Wind	900	0,65%
Other	175	0,13%
Total	**137471**	**100,00%**

Drawing on the information attained in Table 6 (from which it is clear that an overwhelming majority of the electricity produced in Norway is hydro power) a baseline case for the electricity mix in Norway can be created. This will consist of hydropower, wind power, natural gas power and coal power; in total 99,53% of total electricity production. The third largest production technology, after hydro power, biomass power was not included in the baseline case due to lack of data. However, it is expected that this technology will have low emissions compared to e.g. coal power in terms of NO_x, SO_2 and PM and no net emissions of CO_2 (IEA 2010).

4.1.3.2 Full electrification from shore (Alternative 1)

Full electrification is provided by cable from shore. Since this is a high-voltage AC cable it is assumed that losses can be approximated as those in a main grid, i.e. 8,4% (Vattenfall 2005). The emissions caused by the use of cable can be added to those of the energy production technologies. The total electricity production need is calculated to be 8,3 TWh (heat and power for the full life cycle of the platform). The emissions from the baseline case over the full life cycle for full electrification can be seen in Table 7.

Table 7 Life cycle emissions for baseline case for full electrification from shore.

	Baseline case
AP (ton SO2 eq)	129
GWP (kton CO2 eq)	65
EP(ton PO4 eq)	6
POCP (ton C2H4 eq)	95

4.1.3.3 Electrification from shore (Alternative 2)

Electrification is provided from shore and heat is produced offshore by gas fired heaters. As in 4.1.3.2 a loss of 8,4% is assumed. The total electricity needed in this case is approximately 5,17 TWh over the entire life cycle and the heat need is 2,84 TWh. The emissions from this case is presented in Table 8.

Table 8 Life cycle emissions for baseline case for electrification from shore

	Baseline case
AP (ton SO2 eq)	372
GWP (kton CO2 eq)	788
EP(ton PO4 eq)	73
POCP (ton C2H4 eq)	1029

4.1.3.4 Semi-electrification from shore (Alternative 3)

Electrification is partly provided from shore and the energy needed to run the export gas compressor is provided by a gas turbine with waste heat recovery. Also a gas-fired heater is needed to satisfy the maximum heat demand. As in 4.1.3.2 a transmission loss of 8,4% is assumed. The total electricity needed from shore in this case is approximately 2,69 TWh over the entire life cycle and the heat need is 2,84 TWh. The emissions from this case are presented in Table 9.

Table 9 Life cycle emissions for baseline case for semi-electrification from shore.

	Baseline case
AP (ton SO2 eq)	453
GWP (kton CO2 eq)	1682
EP(ton PO4 eq)	105
POCP (ton C2H4 eq)	1476

4.1.3.5 Simple gas turbine (Alternative 4)

All power is generated on the platform by conventional gas turbines equipped with WHRUs that cover the heat demand. The electricity needed is 4,74 TWh and the heat demand is 2,84 TWh. The emissions from this case are presented in Table 10.

Table 10 Life cycle emissions for baseline case for simple gas turbines.

	Baseline case
AP (ton SO2 eq)	**1112**
GWP (kton CO2 eq)	**3070**
EP(ton PO4 eq)	**289**
POCP (ton C2H4 eq)	**4089**

4.1.3.6 Combined-cycle gas turbines (Alternative 5)

All power is generated on the platform by combined-cycle gas turbines equipped with WHRUs that cover the heat demand. The electricity needed is 4,74 TWh and the heat demand is 2,84 TWh. The emissions from this case are presented in Table 11.

Table 11 Life cycle emissions for baseline case for combined cycle gas turbines.

	Baseline case
AP (ton SO2 eq)	964
GWP (kton CO2 eq)	2654
EP(ton PO4 eq)	251
POCP (ton C2H4 eq)	3533

4.2 Sustainability issues

4.2.1 Heat and Power

All heat and power issues are, in this assessment, included in the stressor EICs above.

4.2.2 Waste

The generation of waste falls outside the system boundaries and the scope of this study. For CHP and coal power the emissions from the treatment/disposal of the ash have been included in the life cycle of the energy production.

4.2.3 Raw material use

As discussed in 2.3.3 the construction and the material use shall be evaluated in this BAT assessment. In Table 12 the material for the subsea cable needed in the electrification alternatives and the respective turbine alternatives are presented. It is assumed that the density of the cable is 60 kg/m and that the copper has 33% of the mass and that lead has the remaining 67% (Röstlund 2010). The four simple gas turbines are assumed to weigh 500 tonnes each and the material is assumed to consist to of 100 % steel. The three combined cycle gas turbines are also assumed to consist of 100 % steel and weigh 500 tonnes each and the WHRU an additional 300 tonnes.

Table 12 Raw material use for subsea cable and turbines

Cable material		***Turbine material***	
Density (kg/m)	60	***Gas turbines (ton steel)***	2000
Length (km)	45	***Combined cycle turbines (ton steel)***	1800
Copper share of mass	33%		
Lead share of mass	67%		
Total mass (ton)	2700		
Total copper mass (ton)	900		
Total lead mass (ton)	1800		

The use of any virgin material will have an impact on the environment and the amount of used recycled material in the above installations will reduce this impact. The extraction of metals may leave a large footprint on the local environment and cause large emissions to air and water. Emissions to air from these activities have already been accounted for in the DI, but the impact on the local environment is more difficult to quantify.

If the extraction of all metals is assumed to cause comparable local effects, a comparison of the amount of metals used in the different alternatives can be made. From the data in Table 12 we can see that the electrification alternative would use slightly more metal than the two turbine alternatives. In the context of the construction of an oil and gas platform, this material use can be argued to have little effect on the total ecological footprint, especially if the material used is not virgin and can be recycled at the end of the life cycle. Copper and lead are examples of materials that are often recycled. Drawing on this discussion, raw material use will not be included as an EIC in this BAT assessment.

4.2.4 Energy efficiency

To compare the energy efficiency of the alternatives the total amount of primary energy used to satisfy the platform energy need during the full lifecycle has been summarised. For the alternatives using power from shore we have assumed that it is produced with hydropower. The primary energy carrier in this case is thus water (hydropower) and aspects taken into account are the efficiency in the turbine and losses in the grid from production to platform. For alternatives using natural gas, the efficiencies of the turbines and the heaters are taken into account. The energy needed to extract the natural gas used is not included in the calculations. This process however is considered to be negligible in relation to the energy content in the fuel. The result from the calculation is shown below.

Table 13 Total energy efficiency for the evaluated alternatives

Energy efficiency	***1***	***2***	***3***	***4***	***5***
Primary energy used/FU (EJ)	33	32	35	56	48
Energy carrier	Water	Water	Natural gas	Natural gas	Natural gas
Energy efficiency	82%	85%	78%	49%	56%

As can be seen in Table 13 the energy efficiency of alternative 2 is highest followed by the other electrification alternatives. The reason for the lower efficiency of alternative 4 and 5 is the low electrical efficiency achieved in the gas turbines, especially when running at part load. However, all alternatives show an efficiency of approximately at least 50 % which can be claimed high in relation to other alternative usage of the primary energy. As energy efficiency is a very important parameter when considering energy production concepts, this aspect will be further assessed and compared as one of the EICs.

4.2.5 Decommissioning

Except for hydropower, the emissions from the decommissioning of the onshore energy production technologies have all been included in the DI. Hydropower plants are assumed to be replaced with similar installations when their life span has ended and therefore these emissions are not included (Vattenfall 2005).

The cable used for electrification contains no hazardous material and the copper and lead material, which makes up the bulk of the cable, can be recycled at the end of the life cycle (Röstlund 2010). Emissions from these processes are assumed to be negligible compared to emissions from the whole life cycle of the electrification alternative chosen. The decommissioning of the gas turbines are not included in the assessment as the environmental impact from the recycling of the steel in these installations is assumed to be negligible compared to the total impact during the life cycle of the turbines. Based on this decommissioning is not further assessed and is dismissed as an EIC.

4.3 Environmental risk

No analysis of the environmental risk has been done in this BAT assessment due to lack of time.

4.4 Summary of EICs

Below the results of the EA for the five concepts evaluated are presented in Table 14.

Table 14 Result of environmental and sustainability assessment

	1	*2*	*3*	*4*	*5*
AP (ton SO_2 eq)	129	372	587	1112	964
GWP (kton CO_2 eq)	65	788	1488	3070	2654
EP(ton PO_4 eq)	6	73	140	289	251
POCP (ton C_2H_4 eq)	95	1029	1984	4089	3533
Energy efficiency	82%	85%	78%	49%	56%

As can be seen in Table 14 alternative 1 has the lowest impact in all the environmental categories, and the second highest total energy efficiency. As alternative 1 has the lowest impact, followed by alternative 2 and 3, in all categories the result of the EA is clear.

5 Interpretation

The EA showed that alternative 1 indisputably is the best for the environment as a whole. Also, the gap between alternative 1 and the second best alternative is significant. With this result it is not necessary to prioritize the categories and rank the alternatives as alternative 1 will be best no matter which EIC is prioritized highest.

However the result presented in Table 14 is based on assumptions that will need to be further evaluated. One assumption that has a significant impact on the results is the origin of the power. There are several conflicting methods of dealing with electricity mix issues and stakeholders should question the choice of method. Therefore the sensitivity analysis below will evaluate how the electricity mix affects the results of the EA. This will be done by assuming that all power is delivered from the newly built power generation station at Mongstad. By doing this we will also be able to show how environmental categories could be prioritized and different methods of ranking alternatives.

5.1 Sensitivity analysis

In this assessment a simplified sensitivity analysis will be carried out as no uncertainty analysis has been provided. The sensitivity analysis will be done by altering the origin of power from shore, which is a key parameter with a significant impact on the final result. Below the results of the environmental assessment is shown if all power from shore is assumed to be produced in a gas-fired combined cycle plant, for example at Mongstad.

Table 15 Result of environment assessment with changed power origin

	1	**2**	**3**	**4**	**5**
AP (ton SO2 eq)	480	562	779	1112	964
GWP (kton CO2 eq)	3391	2868	3229	3070	2654
EP(ton PO4 eq)	108	135	194	289	251
POCP (ton C2H4 eq)	1504	1900	2729	4089	3533

As can be seen in Table 15 the result is now more complicated to interpret. Alternative 1 has the lowest impact in all categories but GWP where it is the largest emitter. In this situation it is will be necessary to prioritize between categories to be able to define which alternative is best for the environment as a whole.

5.1.1 Priorities

To prioritize the environmental impact categories according to the relevance of the emissions, will prove difficult in this case as many different types of energy production technologies, with widely differing characteristics are assessed. Therefore, the priorities will be set according to a qualitative analysis.

Of the EICs shown in Table 15, only global warming is a global effect in the sense that it is not dependent upon where the emissions of CO_2 take place. As shown by many recent studies its impacts are potentially significant and severe (IPCC 2007).

Acidification is a regional environmental impact, where oxides of sulphur and nitrogen can be carried thousands of kilometres. In Norway and Sweden, for example, 90 percent of acid deposition originates from outside their borders, mainly from the UK, Germany, Poland and from international shipping. The ecosystems of Norway and Sweden Scandinavia are extremely sensitive to further acid deposition (AirClim 2007).

Historically, the main cause for eutrophication has been discharges of phosphorus and nitrogen compounds to rivers and lakes from agricultural activities. While such discharges may travel long distances via waterways, their effects are often local. Atmospheric deposition of nitrogen compounds also contributes to eutrophication, especially on land and at sea, and as previously mentioned these substances may be carried long distances (AirClim 2007). Eutrophication is a viable problem in most coastal areas of Europe, including the North Sea with fiords and estuaries (EEA 2001).

Human toxicity and photochemical ozone creation potential can be said to be largely local environmental impacts, where emissions are released close to where their effects can be detected.

In Europe the effects from these types of emissions were worst in the Benelux countries, northern Italy, Hungary and Poland while Norway and the northern parts of Scandinavia were relatively unaffected by these problems (AirClim 2008).

Regarding energy production on a platform located in the North sea local effects such as human toxicity and photochemical ozone creation from NO_x, SO_2 and PM will not be an issue due to considerable diffusion (Kelley 2010). Moreover, these are not considered to be serious issues in this region (AirClim 2008).

Gas from the Norwegian continental shelf has a very low SO_2-content. Therefore, the acidification potential coupled with emissions of SO_2 from offshore energy production will be minimal. Depending on where the electricity in the electrification case stems from, acidification may prove an important issue.

As previously mentioned, the most important emissions from the petroleum sector are CO_2 and NO_x. In total, the petroleum sector contributes with approximately 27 and 28 percent of CO_2 and NO_x respectively of Norwegian national emissions (MEP 2007).

Drawing on the above discussion, the prioritization of the environmental impact categories will be done in the following order:

1) Global warming potential
    a. Energy production is closely coupled with emissions of greenhouse gases and a significant amount of research capacity is currently focusing on CO_2-neutral energy production.
    b. CO_2-emissions are of a global nature and energy production at remote locations does not abate the problem.

2) Eutrophication potential
    a. Emissions of NO_x are relatively large from all energy production technologies studied here.
    b. NO_x is one of the most important emissions from the Norwegian petroleum sector.
    c. Eutrophication is a viable environmental problem in coastal areas of the North Sea.
3) Acidification potential
    a. Emissions of SO_2 (and NO_x) are low for most energy production technologies studied in this assessment.
    b. Acidification is still a significant problem in Scandinavia and depending on how much coal power is used emissions of SO_2 may become important.
4) Photochemical ozone creation potential
    a. Mainly local issues that will not prove important for offshore energy production.
    b. These impacts are not an issue in this region.

Implementing the priority recommendations above on the result in the case with power from shore generated in a combined cycle gas-fired plant gives the following table.

Table 16 Result of environment assessment with changed power origin and category priority

	Priority	*1*	*2*	*3*	*4*	*5*
GWP (kton CO2 eq)	**1**	3391	2868	3229	3070	2654
EP(ton PO4 eq)	**2**	108	135	194	289	251
AP (ton SO2 eq)	**3**	480	562	779	1112	964
POCP (ton C2H4 eq)	**4**	1504	1900	2729	4089	3533

5.1.2 Independent number ranking

In this case a statistical method is used to create intervals in each comparison category. This is done by dividing the mean value of the alternatives in the category by the number of alternatives, in this case 5. The first interval is between zero and one interval step, the second interval is between the first interval step and the second etc. The statistical data and intervals for each category are presented in the tables below.

Table 17 Result of environment assessment with changed power origin and category priority

	Max	**Min**	**Average**	**Interval step**
(1) GWP	3391	2654	3042	608
(2) EP	289	108	195	39
(3) AP	1112	480	779	156
(4) POCP	4089	1504	2751	550

Table 18 Result of environment assessment with changed power origin and category priority

	interval 1	interval 2	interval 3	interval 4	interval 5
(1) GWP	<608	608-1217	1217-1825	1825-2434	>2434
(2) EP	<39	39-78	78-117	117-156	>156
(3) AP	<156	156-312	312-468	468-623	>623
(4) POCP	<550	550-1100	1100-1650	1650-2200	>2200

If an alternative is placed in interval 1 it is awared 1 point, if placed in interval 2, two points, and so on. Thus, a low impact gives a low score point and the alternative that is awarded the lowest score environmentally best. This process is shown below in Table 20 for the sensitivity analysis case with power from shore coming from a combined gas-fired plant. The priority previously defined determines which EIC shall be given the highest priority

Table 19 Result of environment assessment with changed power origin and category priority

Ranking	1	2	3	4	5
(1) GWP	5	5	5	5	5
(2) EP	**3**	4	5	5	5
(3) AP	**4**	**4**	5	5	5
(4) POCP	**3**	4	5	5	5

As can be seen in Table 19 all studied alternatives are significant contributors in GWP and were all awarded the highest score in this category. For EP alternative 1 scored 3, alternative 2 scored 4 and the other alternatives all scored 5. For AP, alternatives 1 and 2 scored 4 and the rest 5. For POCP alternative 1 was the lowest emitter, scoring 3 points followed by alternative 2 at 4 points. The other alternatives all scored 5.

The priorities previously discussed concluded that GWP should be given the highest priority. The results from this analysis, however, showed that all alternatives were ranked equal in this EIC. Therefore, the EP will be given the most weight in this interpretation. In this EIC alternative 1 ranks highest, followed by alternative 2. A study of the other EICs (AP and POCP) reveals that alternative 1 also is ranked highest in these. According to the chosen priority and ranking method, alternative 1 should thus be considered best for the environment as a whole. The result also shows that alternative 2 should be considered second environmentally best and alternatives 3-5 are placed equally on third place.

What is also shown is that the sensitivity analysis does not give a different result from the baseline case even though we assume that all power from shore is produced in a gas-fired combined cycle plant.

Alternative 1 is, with high probability, best for the environment as a whole followed by alternative 2.

6 Economic assessment

6.1 Cost-efficiency

The following assumptions have been made in the economic assessment:

Exchange rates

- The exchange rate NOK/€ is assumed to be 7,93 NOK/€.
- The exchange rate NOK/SEK is assumed to be 1,20 NOK/SEK.
- The exchange rate NOK/$ is assumed to be 6,44 NOK/$

Power and gas costs, constants, transmission losses

- Cost of power procurement: 0,36 NOK/kWh (OLF 2007)
- Alternative cost of gas used offshore: 1,68 NOK/Sm^3, which is approximately 0,17 NOK/kWh gas (OLF 2007).
- Discount rate: 6%
- Lifetime: 11 years (Statoil 2006).
- Transmission loss in subsea cable: 8,4% (Vattenfall 2005).

Power consumption and efficiency

- Consumption of power/heat based on data provided by Tjellander (2010).
- The efficiency (e) of the gas turbines vary with their load (L) according to e = 0,0977*L+0,2445. Load and efficiency for each year of operation based on assumptions provided by Tjellander (2010).
- Combined cycle efficiency?

Maintenance costs and taxes

- Maintenance costs for gas turbines and combined cycle gas turbines are assumed to be 3€/MWh. (Tjellander 2010)
- The CO_2 reduced tax (50% for the offshore industry) and the quota price is assumed to be 400 NOK/ton CO_2 (Hoel & Sandgrind 2010).
- The NO_x tax is 15 NOK/kg.

Subsea cable costs

- The cable in the full electrification alternative is assumed to cost 1200 MSEK (Röstlund 2010).
- The cable in the electrification alternative is assumed to cost 1000 MSEK (Röstlund 2010).
- The cable in the semi-electrification alternative is assumed to cost 800 MSEK (Röstlund 2010).

Offshore power production costs

- An offshore gas-fired heater of 24 MW is assumed to cost approximately 93 MNOK (Thørnqvist 2010).
- In the electrification alternative 3 gas-fired heaters of 24 MW are used in order to provide a certain redundancy (Kristensen 2010).
- The gas turbines used are assumed to cost approximately 70 M€ (Tjellander 2010).

- In the semi-electrification alternative it assumed that one gas turbine and one gas-fired heater is needed.
- Four gas turbines are assumed to be needed in the simple gas turbines alternative.
- The cost of the combined cycle concept is assumed to be 120 M€ (Tjellander 2010)

Using the above assumptions the Net Present Value (NPV) for each evaluated alternative is calculated for the project lifetime. The cost-efficiency in relation to emitted CO_2 and NO_x for the different alternatives were then calculated and are presented in Table 20. The least expensive system, in general, and least effective system, in terms of emitted CO_2, is alternative 4: simple gas turbines. This is therefore used as the reference system in order to provide a baseline for cost and CO_2 reduction.

Table 20 Economic assessment of the five alternatives.

	1	*2*	*3*	*4*	*5*
NPV (MNOK)	-3583	-3182	-2890	-2356	-2602
PV CO_2-tax (MNOK)	0	226	471	862	745
PV NO_x-tax (MNOK)	0	6	8	23	20
PV total tax (MNOK)	0	232	480	886	765
Total NPV	-3583	-3414	-3369	-3241	-3367
Reduction cost (MNOK)	341	173	128	0	125
Total CO_2-emissions (kton)	65	788	1639	3070	2654
Reduction (ton CO_2)	3005	2282	1431	0	416
CO_2 cost-efficiency (NOK/reduced ton CO_2)	114	76	89	N/A	301
Total NO_x-emissions (ton)	49	559	779	2224	1928
Reduction (ton NO_x)	2174	1665	1445	0	295
NO_x cost-efficiency (NOK/reduced kg NO_x)	157	104	88	N/A	424
Economic ranking (CO_2)	**3**	**1**	**2**	**5**	**4**
Economic ranking (NO_x)	**3**	**2**	**1**	**5**	**4**

In Table 20, alternative 4 has the lowest total NPV followed by alternative 5 and 3, which only differ by 2 MNOK between them.

When calculating the cost-efficiency of CO_2- and NO_x-reduction, respectively, it is assumed that the whole reduction cost can be allocated to the one stressor. According to Klif reduction measures for CO_2 can be approximated to 1000 – 1500 NOK/ton. This interval is based on estimations of what CO_2 reduction measures could cost if Norway would have to reduce its emissions of CO_2 in order to comply with the proposed 2020 European goal and if two thirds of those reduction measures would be undertaken in Norway. Regarding emissions of NO_x a cost of 50 NOK/ton can be related to historical reduction measures and may therefore be used as a key figure when evaluating cost efficiency. (Sandgrind 2010).

As can be seen in Table 20 the most cost-efficient system, in terms of reduced CO_2-emissions was alternative 2: electrification from shore followed by alternative 3: semi-electrification. Alternative 1: full electrification was found to be a little more expensive than alternative 1 and 2. The least cost-efficient system (excluding the baseline, alternative 4) was alternative 5: combined-cycle gas turbine.

For NO_x, alternative 3 was found to be the most cost-efficient followed by alternative 2. Alternative 1 was significantly less cost-efficient compared to alternative 1 and alternative 5 more than 4 times less cost-efficient. Alternative 5 was, again, the least cost-efficient.

As can be seen in Table 20 the cost-efficiencies for CO_2-reduction are well below the figures given by Klif. This may be due to the fact that the studied systems are all large, high-capacity technologies and that their costs have been discounted. The measures for NO_x-reduction seem to be significantly less cost-efficient compared to the numbers given by Klif when allocated as described above. However, a more realistic allocation method in this case would, perhaps, be to allocate 50% of the reduction cost to CO_2 and 50% to NO_x. This would mean that alternative 1 has a cost of less than 50 NOK/kg NO_x reduced, which is in line with the information from Klif and alternative 2 has a cost 52 NOK/kg NO_x. All other alternatives would have a cost well above 50 NOK/kg NO_x.

It can also be argued that since CO_2-reduction has the highest priority of the EICs, this cost-efficiency measure should be given the most weight in the economic assessment. If only the cost-efficiency of CO_2 is considered, all alternatives are well below the cost-efficiency key figures of future potential reduction measures provided by Klif. Therefore, they can all be seen as economically viable and the NO_x-reduction as a “bonus”.

Alternative 2 is the most cost-efficient in terms of CO_2*-reduction*
Alternative 3 is the most cost-efficient in terms of NO_x*-reduction*

All alternatives are deemed economically viable.

6.1.1 Economic sensitivity analysis

In order to investigate the impact of the discount rate, which may have a large significance in such calculations; it was lowered to 5%. The results are presented in Table 21.

Table 21 Economic assessment with discount rate = 5%

	1	***2***	***3***	***4***	***5***
NPV (MNOK)	-3693	-3273	-2981	-2456	-2696
PV CO_2-tax (MNOK)	0	236	495	911	787
PV NO_x-tax (MNOK)	0	6	9	25	21
PV total tax (MNOK)	0	242	504	936	808
Total NPV	-3693	-3515	-3485	-3392	-3504
Reduction cost (MNOK)	301	123	93	0	112
Total CO_2-emissions (kton)	65	788	1639	3070	2654
Reduction (ton CO_2)	3005	2282	1431	0	416
CO_2 cost-efficiency (NOK/reduced ton CO_2)	100	54	65	N/A	269
Total NO_x-emissions (ton)	49	559	779	2224	1928
Reduction (ton NO_x)	2174	1665	1445	0	295
NO_x cost-efficiency (NOK/reduced kg NO_x)	138	74	64	N/A	379
Economic ranking (CO_2)	3	1	2	5	4
Economic ranking (NO_x)	3	2	1	5	4

As can be seen in Table 21 the total NPVs of the alternatives have changed. Their internal order has not changed, however. The cost-efficiencies of the alternatives change but not their relative order.

The discount rate is then changed to 7% and the results are presented in Table 22.

Table 22 Economic assessment with discount rate = 7%

	1	*2*	*3*	*4*	*5*
NPV (MNOK)	-3481	-3098	-2805	-2263	-2515
PV CO_2-tax (MNOK)	0	217	449	817	706
PV NO_x-tax (MNOK)	0	6	8	22	19
PV total tax (MNOK)	0	222	457	840	725
Total NPV	-3481	-3321	-3262	-3102	-3240
Reduction cost (MNOK)	379	218	160	0	137
Total CO_2-emissions (kton)	65	788	1639	3070	2654
Reduction (ton CO_2)	3005	2282	1431	0	416
CO_2 cost-efficiency (NOK/reduced ton CO_2)	126	96	112	N/A	330
Total NO_x-emissions (ton)	49	559	779	2224	1928
Reduction (ton NO_x)	2174	1665	1445	0	295
NO_x cost-efficiency (NOK/reduced kg NO_x)	174	131	111	N/A	466
Economic ranking (CO_2)	3	1	2	5	4
Economic ranking (NO_x)	3	2	1	5	4

In Table 22 it can be seen that the difference between the total NPVs of the alternatives increases due to costs and taxes being discounted more. The cost-efficiencies change but the relative order of the alternatives remains the same.

7 Technical assessment

7.1 Full electrification from shore

A solution where the platform is fully electrified can either be based on one DC cable or two AC cables. A DC cable solution would require an inverter to be installed on the platform, which could be problematic due to weight and space restrictions. These restrictions would also apply to the two-AC-cable-solution where e.g. an additional transformer would have to be installed to accommodate the second cable connection (Statoil 2006, Palm 2010). Of these two alternatives the two-AC-cable solution is considered as more beneficial for shorter distances to shore such as this (45 km) (Eni Norge 2008).

As of today there exist no accepted verification standards for electrification of platforms via subsea cables (Palm 2010). The technical difficulties lie mainly in the fact that the position of a floating platform such as Gjøa will not be fixed due to waves and currents. Therefore, the part of the cable from the sea bottom to the platform must be designed with dynamic properties, which makes the system more complex and expensive. At large depths the weight of the cable will also pose problems (Palm 2010). The Gjøa platform is located at a depth of 360 m and therefore this should not be a restriction in this specific case. However, strictly speaking there are no technical restrictions in designing such a system and similar solutions have already been chosen for existing or planned platforms. What is limiting the use of electrification cables is instead their cost (Palm 2010; Röstlund 2010).

In an environmental impact assessment from 2006 a power capacity of 45 MW were guaranteed by the local power grid company (Bergenshalvøens Kommunale Kraftselskap, BKK) at the chosen connection point of Mongstad (Statoil 2006). With the construction of a natural-gas combined heat and power plant, which will come online in 2010, this capacity will increase significantly. The new power plant will have a production capacity of 280 MW electricity and 350 MW heat (Statoil 2007). Therefore, full electrification of the Gjøa platform should not be limited by the power availability in the grid at the connection point in Mongstad.

With full electrification no major redundancy power capacity would be available on the platform in case of a power failure. Therefore, the risk for emergency flaring increases significantly with this solution. Emergency systems such as diesel generators are able to uphold some functions such as the prevention of oil discharge to sea for shorter failures. In case of longer power failures, however, a worst-case scenario means that oil is discharged directly to sea (Eni Norge 2008).

Full electrification from shore is considered to be technically available.

7.2 Electrification from shore

Similarly to full electrification, electrification from shore could either be accomplished by one DC-cable or two AC-cables, where the AC-solution is more likely (Statoil 2006).

The same technical possibilities and difficulties exist for this solution as with full electrification. The required power capacity is lower than for full electrification.

The same reliability risk issues as for full electrification apply to the electrification alternative.

Electrification from shore is considered to be technically available.

7.3 Semi-electrification from shore

In a solution where the platform is partially electrified a power capacity of 39 MW is required. In such a concept a single AC-current cable would be sufficient (Statoil 2006, Eni Norge 2008). A single cable would mean a less complex system, which would require less space and weigh less; two significant aspects on any oil and gas platform (Statoil 2006; Kirkeng 2010). In addition, the same technical difficulties from the dynamic position of the platform and the weight of the cable described in 7.1 apply to this solution. The required power capacity is lower than for full electrification and electrification.

In this alternative there is a certain redundancy in the power generation capacity of the platform. This means that in case of a power failure, emergency systems may be upheld by the gas turbine, which means that flaring and oil discharge may be avoided (Eni Norge 2008).

Semi-electrification from shore is considered to be technically available.

7.4 Offshore energy production with simple gas turbine cycle fitted with waste heat recovery

This solution consists of four gas turbines with WHRUs and gas-fired heaters. The technology required for this solution is industry standard in the petroleum sector and similar systems have been in use for at least 15 years. There would be a certain redundancy in the system and in case one of the turbines should fail emergency systems could easily be upheld.

Offshore energy production with simple gas turbine cycle fitted with waste heat recovery is considered to be technically available.

7.5 Offshore energy production with combined gas turbine cycle fitted with waste heat recovery

This system is made up of three combined cycle gas turbines connected to a steam turbine and a gas-fired heater. The technology required in this solution has found use in many onshore installations for energy production where it is considered to be conventional technology. So far it has not been used for new offshore energy production installations. A conversion to offshore application would not prove difficult according to suppliers and is currently being investigated (Tjellander 2010).

Offshore energy production with combined gas turbine cycle fitted with waste heat recovery is considered to be technically available.

8 Final assessment

Already in the EA it was clear that alternative 1 was best in all EICs but one. Alternative 2 was ranked as second in all EICs, alternative 3 third in all EICs and so on.

The economic assessment showed that alternative two had the highest cost-efficiency for CO_2-reduction and alternative 3 the highest cost-efficiency for NO_x-reduction. All alternative were considered to be economically feasible.

The technical assessment showed that all alternatives were, in principal, technically available. In the full electrification alternative the platform is completely dependent on the subsea cable. There are no backup systems in case of cable failure. Installing additional backup systems may prevent this, but all these efforts would aim to cover the heat demand by electricity instead of by gas combustion offshore. The process of converting high-quality energy such as electricity to heat is questionable and gas combustion is highly efficient (>90 %). Therefore alternative 1 is not deemed to be a feasible solution.

Alternative 2 is considered to be BAT because it has a low environmental impact in all EICs, and would not convert electricity to heat as discussed above. Therefore, alternative 2 is considered to be best for the environment as a whole. Further, it has the highest cost-efficiency for CO_2-reduction, which was given the highest priority in this assessment. Cost-efficiency will be very important for any company. It is deemed to be technically available, but an in-depth risk analysis should be performed in order to evaluate the consequences of a subsea cable failure. Potentially, a backup gas turbine can be installed in order to reduce this risk as a first economic assessment showed that this would still be economically feasible[*]

Alternative 2: Electrification from shore is Best Available Technique.

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[*] The CO_2 cost-efficiency would be reduced to 136 NOK/reduced ton CO_2.

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Appendix B Example BAT assessment – Bilge Water Treatment

Table of contents

1 Introduction

The purpose of doing this Best Available Technique (BAT) assessment was to familiarize ourselves with the methodology and start building up the DNV guideline on BAT. It should be emphasized that this BAT assessment mainly was done before the DNV guideline was written. In many modules a simplified version of the required analysis is given and some content is missing altogether. Therefore, this example should not be viewed as complete and representative for a full BAT assessment. For a full picture of BAT assessment please refer to the DNV guideline.

1.1 Definitions

Assessor	The person(s) doing the assessment on Best Available Techniques
Available techniques	Developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced in the Member State in question, as long as they are reasonably accessible to the operator (2008/1/EC)
Best	Most effective in achieving a high general level of protection of the environment as a whole (2008/1/EC)
CO_2	Carbon dioxide
DNV guideline (on BAT)	Guideline on BAT for implementation on oil and gas platforms written by the autors
Environmental Assessment (EA)	The process of categorising and characterising the data gathered in the DI
Environmental Impact Category (EIC)	The effect on the environment caused by the emission/discharge of a certain stressor or sustainability issue or environmental risk
Environmental Impact Assessment (EIA)	Document that must be handed in to and be approved by authorities for all projects that may have a significant impact on the environment. This includes all offshore installation projects.
Interpretation	The process of analyzing the information in the EA
Data inventory	The process of gathering information on a certain technique
NO_x	Nitrogen oxides, refers to a mixture of NO and NO_2

Platform	The physical installation used for oil and gas production offshore
Rig	See platform
SO_x	Sulphur oxides, refers to one or more of various sulphur oxide compounds, mainly SO_2
Stressor	An emission or discharge, which leads to one or several environmental impacts
Techniques	May refer to both a technology and the way in which the installation is designed, built, maintained, operated and decommissioned (2008/1/EC)
Technology	Tools, machinery or a system of machinery created to fulfil a specific function

1.2 Abbreviations

AP	Acidification Potential
BAT	Best Available Techniques
CO_2	Carbon dioxide
DI	Data Inventory
DNV	Det Norske Veritas
ECM	IPPC Reference Document on Economics and Cross-Media Effects
EA	Environmental Assessment
EIC	Environmental Impact Category
EP	Eutrophication Potential
FEED	Front End Engineering and Design
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention and Control
LCA	Life Cycle Analysis
nmVOC	non-methane Volatile Organic Compounds
NO_x	Nitrous Oxides
PM	Particulate Matter
POCP	Photochemical Ozone Creation Potential
SO_x	Sulphur Oxides

2 Scope & boundary definition

This BAT assessment shall evaluate various systems for bilge water treatment on oil and gas rigs.

2.1 Site specific conditions

The target rig is located on the Norwegian continental shelf and Norwegian laws and regulation apply.

2.2 Theoretical definitions

Bilge water is produced when water used for washing internal structures on a ship gathers in compartments in the lower region of the hull, which must later be pumped out. Nowadays, bilge water is often collected in purposefully built tanks. The term has been transferred to oil and gas rig operations and is used to describe water gathered in the hull of the rigs when cleaning their machinery (Glimmermann 2006).

Bilge water may contain a variety of chemicals and can be said to have a heterogenic composition. Chemicals may include:

- Oil/grease
- Oxygen-demanding substances
- nmVOCs
- Inorganic salts
- Metals

The phenomenon of emulsion occurs when mixing two non-blending liquids. In the case of bilge water the mixture contains water and a combination of different oily compounds. Because of the different chemical properties of oil and water, oil is insoluble in water. Instead it forms small drops in the water phase, creating an emulsion. The aim of offshore bilge water treatment is to separate the oil from the water so that the purified water could be discharged to sea (Glimmermann 2006).

2.3 Environmental impact

Compared to produced water, bilge water releases to sea are usually minimal (OLF 2009) but can under condition when water injection is used be of considerable amount. The environmental aspects of releasing treated bilge water to sea are limited to the immediate surroundings of the rig and its consequences are generally considered to be negligible. Long-term effects may prove most problematic, but even here current research shows that these will not have a significant impact (Eni Norge 2008).

Organisms, such as mussels and cod, at stations a few hundred meters from the station were shown to be affected by discharge of produced water. It was also shown that, for these organisms, there were moderate negative effects. It was, however, not possible to determine the consequences for the organisms (OLF 2009).

There are also indirect environmental aspects to consider when evaluating technologies for bilge water treatment. These include the generation of hazardous waste such as used filters (in some systems) and the use of energy; power, steam, and heat. Energy generation, whether offshore or onshore, may lead to emissions of CO_2, NO_x and SO_x to mention a few. These aspects will also have to be considered in the evaluation of the environmental performance of the technology.

2.4 Significant environmental impact

Oil discharge to sea is a significant environmental impact of oil and gas operation. Other significant impacts from oil and gas platforms include emissions to air from energy production.

2.5 Constraints

The following requirements and constraints have been identified for the bilge water system.

2.5.1 Regulatory constraints

- IMO
    - Mobile, self-propulsive platforms (Haukebø 2010)
    - Limit of 15 ppm of oil in bilge water released to sea (IMO 2009)
    - System must be able to handle any oil mixtures and expected to be effective over the whole range of oils and deal with emulsion of these (IMO 2009)
    - The system should have a 15 ppm bilge alarm (2009)
- NORSOK S-003
    - No regulation applicable to bilge water

2.5.2 Need & capacity constraints

To be able to separate oil from water the emulsion needs to be broken or reduced. Its stability is governed by a number of factors that can be altered to break the emulsion. These parameters are among others, droplet size, particles in the solution and presence of surface active substances. (Glimmermann 2006)

When the emulsion is broken or the drops have been gathered to form larger aggregates of oil the actual physical separation of the oil from the water can take place. The separation can be done by using a number of techniques.

Generally the separation of oil and particles in the bilge water has a few typical process components. These are made up of the bilge tank, sludge tank, the cleaning unit, and a monitoring unit to control the concentration of oil in the cleansed water before discharge. If the desired level of cleaning is not achieved when the stream passes the monitoring unit it can be re-injected in the beginning of the process. The figure below shows the principal schematic and flows.

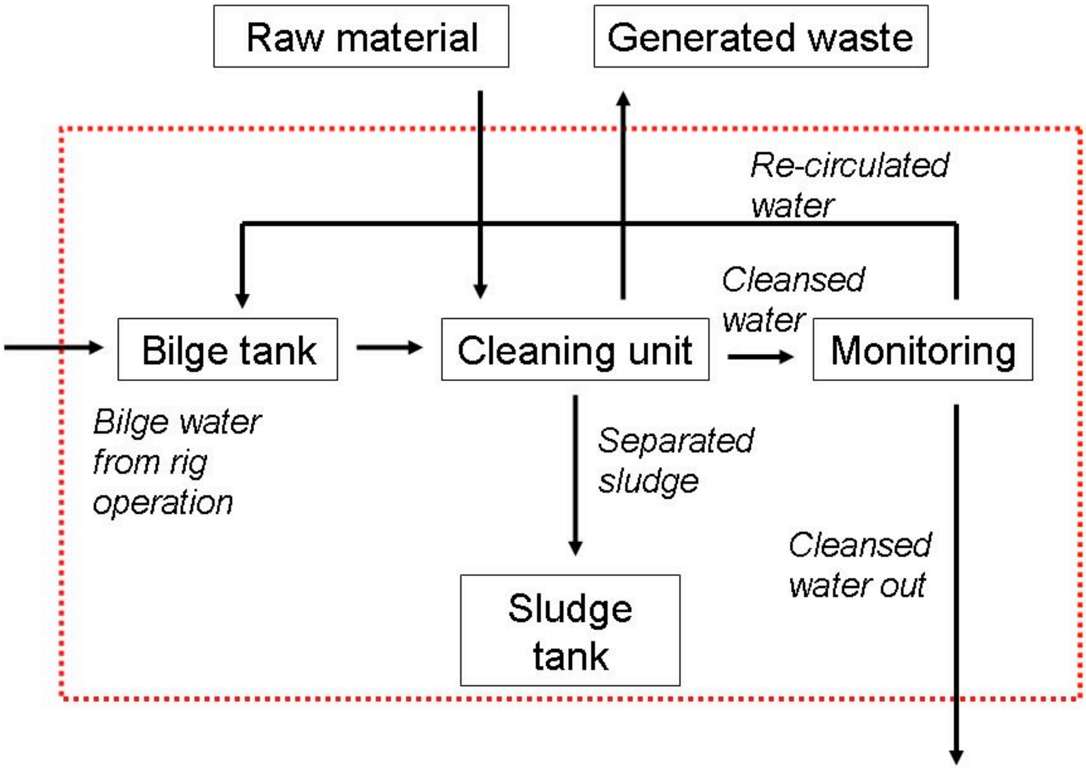


Figure 25 Schematic of a general bilge water treatment system with system boundaries.

The bilge water from the platform operation is generally gathered in a bilge tank and then the flow goes from the bilge tank through the cleaning unit where oil and water are separated. The separated oil goes to a sludge tank and the cleansed water is controlled to make sure it is below the limit before it is discharged to sea. In an oil production facility the oil in the sludge tank generally can be injected in the produced oil process. In a facility only producing gas the oil in the sludge tank cannot be injected in the production process and hence has to be handled as waste. Depending on the size of the tank, and water content in the separated oil the sludge tank is usually emptied a few times a year. The content is then transported to shore together with other wastes for further treatment, deposition, or incineration. In Norway the most common technique to handle the waste is incineration with energy recovery in the process. (Kelley 2010)

Depending on the technology used in the cleaning unit, waste could also be generated in this stage if the process uses filter and/or absorption materials. When these are full they have to be changed and the used will be disposed as hazardous waste that needs to be taken ashore for treatment.

The main purpose of bilge water treatment system is to cleanse bilge water from oil before it is released to sea.

- Bilge water production
    - 3 – 5 m^3/day
- Weather conditions

Systems should be able to comply with offshore conditions including temperatures down to minus 10 ° C and high level of saltwater spray.

2.5.3 System boundaries

As can be seen in Figure 25 the system boundaries have been defined from the intake of bilge water from operation to the disposal of separated oil in the sludge tank, cleansed water to sea and generated waste. Furthermore, the energy consumed by the system and material used in the construction/operation of the system shall be considered. These aspects are assumed to be of the same origin.

2.5.4 Functional unit

The functional unit in this BAT assessment is defined as g oil reduced in released/treated water.

3 Data inventory

3.1 Technique screening

The different techniques described here will be based on existing bilge water separation systems from different manufacturers. For the purpose of this example BAT they have been simplified and shall not be viewed as representative neither for the technology of the individual manufacturers nor for bilge water treatment in general.

3.1.1 System A – Disc Stack Centrifuge

Separation may be accomplished by settling through gravity, the settling speed may be increased by increasing the force acting on the fluid. This is based on Stoke's law which states that an increase in the gravitational force will lead to an increase in the settling velocity (Glimmermann 2006).

The disc stack centrifuge is commonly used to separate liquids from one another and from fine emulsions of solid particles (Glimmermann 2006). System A is based on the Ecostream by Alfa Laval and comprises four main functions (Alfa Laval 2010):

- Forwarding/pumping
- Oily water pre-treatment
- Centrifugal separation
- Process control and monitoring

Oily water is pumped from the settling tank to the pre-treatment stage and can provide a feed range from 1.5 – 2 m^3/h. In the pre-treatment larger particles are trapped first mechanically and then the fluid passes through a heat exchanger that raises the temperature to 60 – 95 °C. A chemical dosing unit may be connected at this stage (Svensen 2010).

When all conditions are met, the fluid is introduced into the separation chamber where it is centrifuged (Alfa Laval 2010). The denser liquids will be forced to the walls of the centrifuge whereas the less dense liquids will form concentric inner layers (Glimmermann 2006).

Oil and emulsion are continuously separated from the water and directed to a sludge or waste-oil tank. Treated water is also discharged continuously and an oil-in-water monitor measures the oil content to ensure it complies with regulation (IMO). When the oil is below the regulation value (15 ppm) the treated water can be directed either to a holding tank or overboard. If the treated water is above this value the water is re-circulated to the bilge water settling tank.

Table 23 Performance data for System A (Alfa Laval 2010; Svensen2010).

	System A
1. Reduction rate (ppm)	5-10
2. Energy use, power and steam (kWh/m3)	Elec: 2,5 Steam: 69
3. Steel used in production (kg)	1510
4. Generated waste in operation	Sludge
5. Chemical use in cleaning process	Iron salts, polymeres

3.1.2 System B – Vacuum evaporation

Evaporation is a common and historically often used method of separating oil and other material from water. Since water has a lower vapour pressure than oil it will evaporate faster, leaving the oil as a residue in the evaporation tank. Offshore, this method is too space- and time-consuming and in order to speed up the process a combination of heat and vacuum can be used. The water vapour stream can then be condensed in a highly pure water stream while the condensate of contaminants can be disposed or stored (Glimmermann 2006).

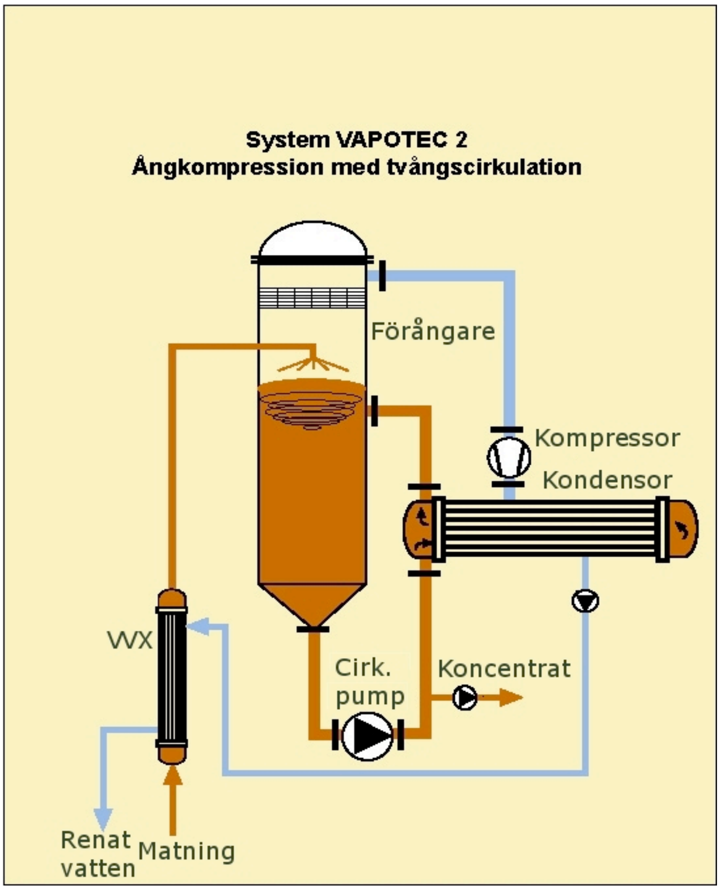


Figure 26 The Vapotec 2 system (Vapotec 2010)

System B is based on Vapotec 2, which is designed to operate at temperatures of 60 – 70 °C and pressures of 200 – 300 mbar. In the Vapotec 2 system the bilge water is pre-heated by the outgoing stream of condensate. The energy used in the evaporation pressure is re-used after compression to the ingoing stream of bilge water. Thus, virtually no other energy has to be supplied than that needed for the pumps (Vapotec 2010).

Table 24 Performance data for System B (Vapotec 2010; Hedqvist 2010).

	System B
1. Reduction rate (ppm)	15/5
2. Energy use, power and steam (kWh/m3)	35-50
3. Steel used in production (kg)	2000
4. Generated waste in operation	Sludge
5. Chemical use in cleaning process	Non used

3.1.3 System C – Two stage separation system

System C is based on the Mahle separation system and is made up of two separation stages both different from the previous systems discussed. The first one uses gravity, coalescence and flow as separation techniques and the second is a special filtration bed, primarily based on coalescence.

Coalescence is based on colloidal properties and the fact that two separate drops may have the same volume as one large but the larger drop will have a smaller surface area. In a mixture of oil and water a system with smaller surface area is favoured by having a lower state of energy and therefore the coalescence process is spontaneous. The merging of smaller drops into larger makes it easier to separate oil from water and therefore the process of coalescence is useful in separation technologies (Glimmermann 2006). In the MPER separation system coalescence is enhanced by the use of patented oleophilic (oil loving) materials that bond to the dispersed oil (Scholz 2010).

In the first stage the main drives for separation is gravity and coalescence. A pump increases the pressure of the untreated stream and then leads it through a number of inserts which are made up of 10-15 wave type profiles, meaning plates of oleophilic material that are bended to trap and separate oil and solids from the water. The surface of the profiles bonds to the oil drops and make them merge into larger drops. Then the larger drops are pressed up along the profiles to the centre where they are collected in the first oil dome. The solids and heavier substances are also separated in the profiles and forced to the bottom where they are collected in the sludge tank. The figures below describe the process in the first separation stage (Mahle 2010).

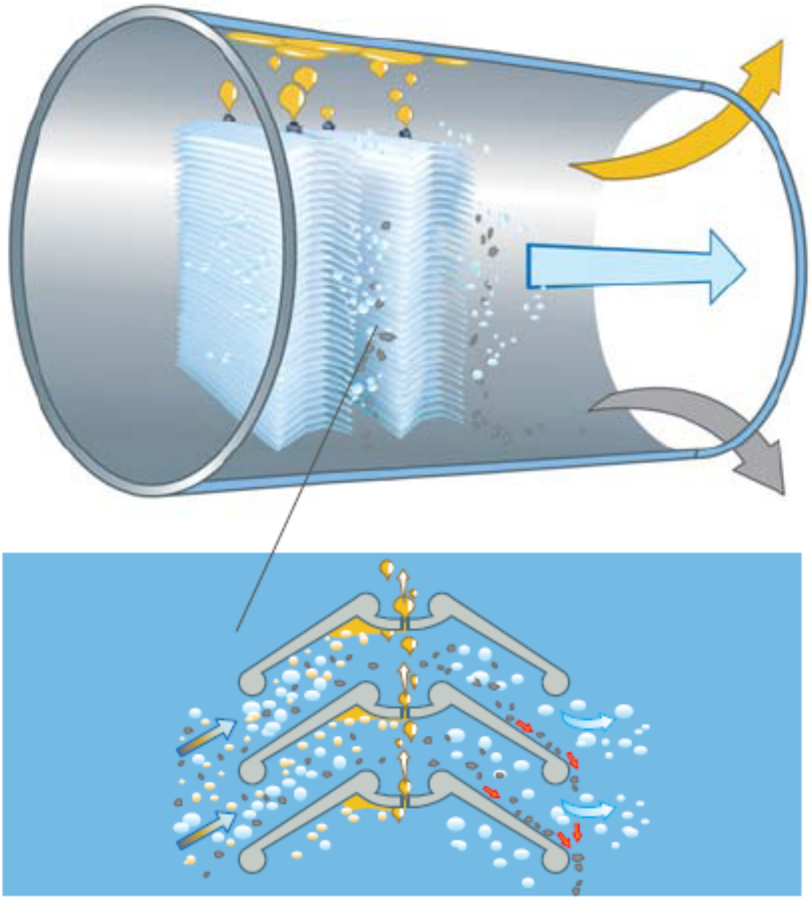


Figure X. The first separation stage of the MPEB separator (Mahle 2010)

The second stage of separation is designed to break the emulsion of dispersed oil. The stream is fed to a number of cylinders coated with a special oleophilic fibre material. The number of cylinders varies between 2 -12 depending on application. The stream is forced through the fibre material from the inside to the outside trapping oil droplets greater or equal to 1 μm. In the fibre bed the small separated drops merge to form larger drops and are then forced up and collected in the second oil dome. The figure below shows the process of the second separation stage.

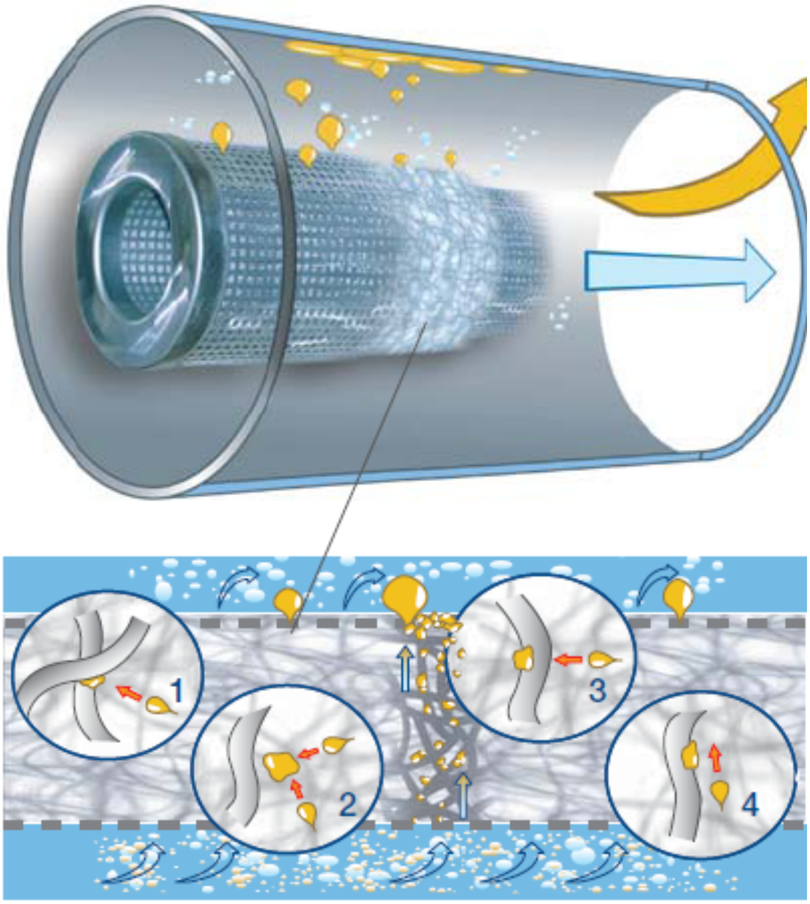


Figure X. The second separation stage of the MPEB separator (Mahle 2010)

After the second separation stage the purified water stream is controlled to ensure the oil content is less than 15 ppm of oil content before it is discharged to sea. If oil content is higher than 15 ppm the stream is re-injected back into the bilge water tank to go through the process again.

Table 25 Performance data for System C (Mahle 2010; Scholz 2010).

	System C
1. Reduction rate (ppm)	<15
2. Energy use, power and steam (kWh/m3)	3
3. Steel used in production (kg)	1000
4. Generated waste in operation	Sludge + filter change every 18-24 months
5. Chemical use in cleaning process	Non used

3.1.4 System D – Four stage separation system

System B is based on the Wärtsilä Senitec system for marine applications and consists of a 4 stage bilge water treatment unit able to separate highly concentrated bilge water to a guaranteed level below 5 ppm (Olsson 2010). The four stages include the following measures:

- Air flotation and skimming
- Coagulation and flocculation
- Air flotation and skimming
- Carbon filtering

In the first flotation stage compressed air is injected in the bottom creating air bubbles that force oil to the top of the container as they move towards the surface. The oil is gathered at the surface as skim and is removed mechanically. In the second stage chemicals are added to break the emulsion in the solution and to separate solids. The coagulation chemicals are typically cat ions that neutralize the negative charge on the dissolved particles and droplets in the solution making it possible for them to aggregate into larger clusters. This is usually done in sequence with adding flocculation chemicals which bind the clusters together into larger particles. When the added chemicals have gathered the solids and small drops they are easier to separate. In the third stage physical separation of these is accomplished by repeating air floatation and skimming (Wärtsilä 2010).

The fourth and final stage is carbon filter filtration. When the oil and water stream reach this stage the oil concentration is usually very low, also lowering the load on the filter. Besides reducing the oil concentration in the stream the Senitec system also cleanses the stream from CODs (chemical oxygen demanding substances) and heavy metals. Through the process the separated oil is gathered in a sludge tank and the process also can be complimented with a system gathering and drying the separated solids. Before the cleansed water stream is discharged to sea a *Bilge guard* unit controls that the concentration is below the specified level. According to Wärtsälä tests have shown that before the filtration stage the oil concentration usually is around 1 ppm and after filtration below 1 ppm (Olsson 2010).

Table 26 Performance data for System D (Wärtsälä 2010; Olsson 2010).

	System D
1. Reduction rate (ppm)	<5
2. Energy use, power and steam (kWh/m3)	4
3. Steel used in production (kg)	950
4. Generated waste in operation	Sludge + sand filter change every 24 month+dry waste
5. Chemical use in cleaning process	Polyamides, AlCl, NaOH

3.2 Data quality

The data for the different alternatives in this BAT assessment has been gathered from the manufacturers of the systems. Data has been attained from both printed product catalogues as well as during first-hand interviews with each of the suppliers. The data is therefore assumed to be of equal quality and adequate accuracy.

4 Environmental Impact Assessment

4.1 Stressors

As this system is an end-of-pipe solution aiming to reduce the oil content of bilge water, there is only one relevant ECM environmental impact category: aquatic toxicity. In this case aquatic toxicity shall be simplified as the reduction rate of oil in bilge water. Added chemicals could have been an EIC. However, during the DI it was discovered that these are common water treatment chemicals with a benign nature (Svensen 2010; Olsson 2010). Therefore they have been excluded from the assessment.

4.2 Sustainability issues

4.2.1 Energy efficiency

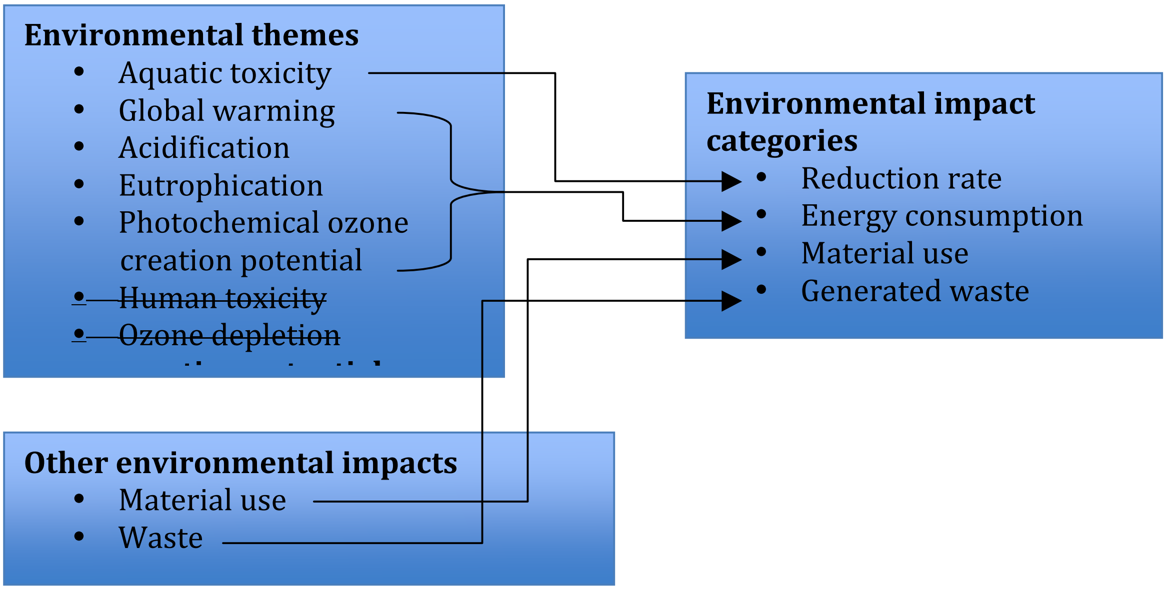
Other impacts can be related to the technique indirectly through its energy consumption/energy efficiency. This aspect shall also be covered by the assessment. The energy used on the platform stems from the same source and therefore emissions from energy use can be simplified to the energy efficiency of the evaluated technique.

4.2.2 Raw material use

As the studied systems are primarily made of steel, which is a material with considerable environmental effects, this should also be a category included in the evaluation. This evaluation will be simplified by looking at the total mass of the installation as it is assumed to make up most of the weight.

4.3 Waste

Sludge is generated in all four alternatives. Two of the studied systems have filters that must be changed approximately every other year. As the systems will be installed on a production platform the sludge will most likely be injected, as this is now standard practise (Kelley 2010). The only remaining generated waste from the bilge water systems is therefore the filters in two of the alternatives. An average platform generates approximately 50 tonnes of hazardous waste per year. The filters from the bilge water treatment systems are assumed to make up an insignificant part of this mass.



4.4 Environmental risk

No major environmental risk has been identified in the evaluated techniques.

4.5 Summary of EICs

In Table 27 the results of the DI have been summarized into the four EICs.

In the first comparison category, reduction rate, a mean has been taken for System A. The reduction rate of System B has been set to below 5 ppm as this is a possibility according to the supplier. It has been assumed that this enhanced reduction rate will lead to a higher energy consumption level (50 kWh/m^3). As mentioned above the the use of chemicals has been assumed to be insignificant in this assessment and therefore this EIC has been excluded.

Table 27 Summary of EICs.

	System A (rank)	***System B (rank)***	***System C (rank)***	***System D (rank)***
1. Reduction rate (ppm)	7,5 (2)	5 (1)	15 (3)	5 (**1**)
2. Energy use, power and steam (kWh/m3)	Elec: 2,5 Steam: 69 (4)	50 (3)	5 (2)	2 (**1**)
3. Steel used in production (kg)	1510 (2)	2000 (3)	1000 (**1**)	950 (**1**)
4. Generated waste in operation	Sludge (**1**)	Sludge (**1**)	Sludge + filter change every 18-24 months (2)	Sludge + sand filter change every 24 month+dry waste (2)
Summary	9	8	8	5

5 Interpretation

5.1 Priorities

As previously mentioned the significant environmental impacts on an oil and gas platform are discharge of oil to sea and emissions to air related to energy production. The corresponding EICs in this assessment are reduction rate, and energy consumption, which makes these EICs the most important to consider. In order to prioritize these two categories a comparison of their impact relative the platform total shall be made. As this is a rudimentary example estimated data from Goliat shall be used. Where data from Goliat could not be found, average data from OLF from platforms on the Norwegian continental shelf has been used.

5.1.1 Reduction rate

In order to relate the amount of discharged oil to the total oil discharge of the platform, data for Goliat's expected discharge of produced water was used. The estimated discharge of produced water to sea is 90000 m^3/year containing an average oil concentration of 10 ppm (Eni Norge 2008). Looking at the total volume of oil this corresponds to 0,9 m^3 of oil discharged per year. However it should be noted injection of produced water is planned on Goliat and therefore this volume is rather low.

The reduction rates for the assessed techniques differ from 5 ppm – 15 ppm oil concentration in discharged water. The mean for the technologies is 8,125 ppm. If we assume that 1 m^3 of bilge water is handled per hour; 8760 m^3 of water is handled annually. Multiplying the mean value, 8,125 ppm, with this value the amount of discharged oil per year is approximately 0,07 m^3. Comparing this amount with the total for Goliat the bilge water discharge of oil corresponds to approximately 8 % of the total discharged oil.

5.1.2 Energy consumption

If we assume that the power demand on Goliat is at its maximum of 38 MW and that the heat demand is at 32 MW constantly all year the total energy consumption can be approximated to 780 GWh per year (Eni Norge2008).

The energy consumption of the four evaluated technologies for bilge water treatment varies from 3 to 71,5 kWh/m^3 treated water, with a mean of approximately 32 kWh/m^3 treated water. We assume 1 m^3/h of treated bilge water. The energy consumption can then be approximated to 0,3 GWh/year. Comparing this amount with the total annual expected energy consumption, the bilge water energy consumption accounts for approximately 0,05 % of the total energy consumption.

5.1.3 Prioritizing EICs

Relating these categories to the total corresponding impact above shows that reduction rate should be given priority above energy consumption as its share of the total impact is in the order of >100 times greater than the corresponding share for energy consumption. The remaining environmental categories will in this evaluation be assessed after reduction rate and energy consumption without internal priority.

5.2 Ranking

In this assessment a relative internal ranking has been used and the results of this are bracketed in Table 27. The “scores” are summarized in the last row of Table 27. According to these scores system D is environmentally best alternative.

If a more qualitative ranking method is to be used we can start by looking at the priorities previously defined. As can be seen in Table 27 system D is the best performer in both reduction rate and energy consumption. Therefore, there is little doubt that, of the evaluated alternatives, system D is best for the environment as a whole.

System D is the environmentally best alternative.

6 Economic assessment

The purpose of a bilge water treatment system is to cleanse bilge water from oily compounds. Therefore a cost efficiency analysis should consider the cost per reduced amount of oil, The result of this assessment is displayed in Table 28 below. It should be emphasized that the investment costs (CAPEX) are very rudimentary. Moreover, the economic assessment is based on the following assumptions:

- We assume that operational costs (OPEX) are similar for all installations and insignificant relative to the investment cost (CAPEX) and can therefore be disregarded in this analysis.
- The untreated bilge is assumed to contain 30 % oil with an average density of 900 kg/m^3.
- The flow is set to 1 m^3 bilge water/hour.
- The operational lifetime of all evaluated systems is assumed to be 10 years.

Table 28 Cost-efficiency of studied bilge water treatment systems.

	System A	***System B***	***System C***	***System D***
Investment cost (NOK)	500000	2500000	300000	850000
Reduction kg oil/m3	269,99325	269,9955	269,9865	269,99325
Cost-efficiency (NOK/reduced kg oil)	0,021	0,11	0,013	0,036

As can be seen in Table 28 system B has the lowest cost-efficiency of the studied alternatives. System D has a significantly higher cost efficiency compared to B but is still relatively expensive compared to C. Systems A and C have comparable levels of cost efficiency, but still system C emerges clearly as the most cost-efficient per kg oil reduced during the lifetime of the system.

A comparable system to C has been chosen and installed for a platform under similar conditions. Therefore, it is deemed to be an economically viable solution (Kelley 2010). System D has, however, also been installed under comparable conditions and should therefore also be viewed as economically feasible, albeit with a lower cost-efficiency (Olsson 2010).

System C is the most cost efficient.
Systems C and D are deemed technically viable.

7 Technological assessment

Systems A and C have been in use for approximately 5 years and have already found a number of applications offshore. System A is currently in use on approximately 20 offshore installations. System C has been installed on offshore drilling rigs, but it is unknown how many. System D has found applications on approximately five offshore drilling rigs. System B has not been installed in any offshore applications but is currently being tested on two freighter vessels.

In terms of technical viability systems A, C and D can be said have an equally acceptable record of technology maturity.

Systems A, C and D are deemed technically viable

8 Final assessment

As was shown in the interpretation module, system D was judged best for the environment as a whole. It had the lowest aggregated score and was ranked first in reduction rate, the most important EIC. Also it was ranked first in energy use, the second most important EIC.

The economic assessment, however, showed that system C was the most cost-efficient alternative. It also showed that systems C and D were economically viable.

The technological assessment concluded that systems A, C and D were all technically feasible.

As system D is deemed to be both technically and economically feasible it is considered to be the best available technique for bilge water treatment on this platform.

If the project owner should deem this alternative to be economically unviable and is able to prove this, the recommendation would be to choose System C because this showed the highest cost efficiency and although it has a reduction rate three times lower, it complies with the regulatory demand of 15 ppm and has a comparably low energy consumption. Under such circumstances System C could be considered to be best available technique for bilge water treatment on this platform.

System D is BAT for bilge water treatment on Goliat.

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