Emissions Reduction Workflow for New FPSO Development

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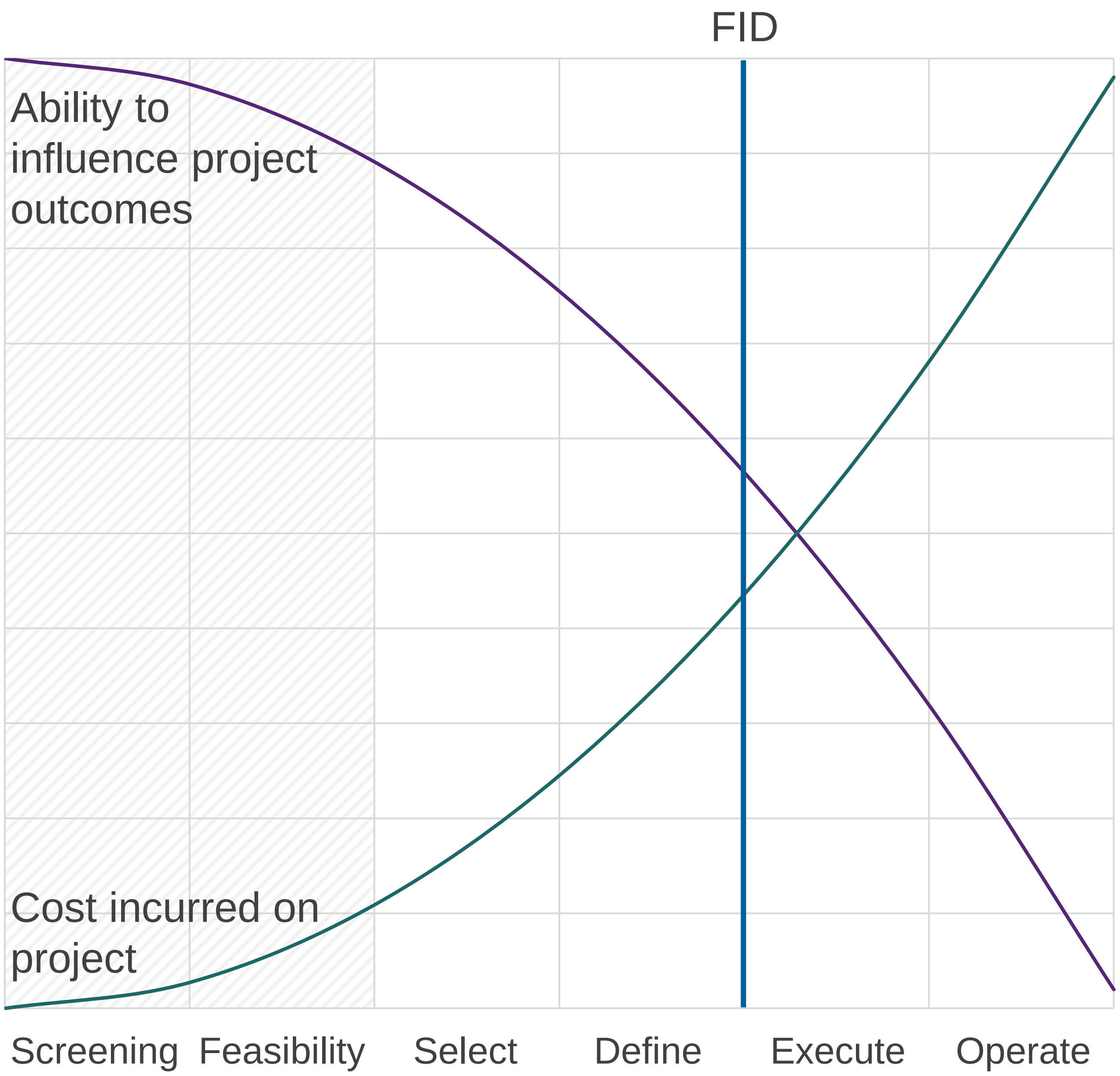
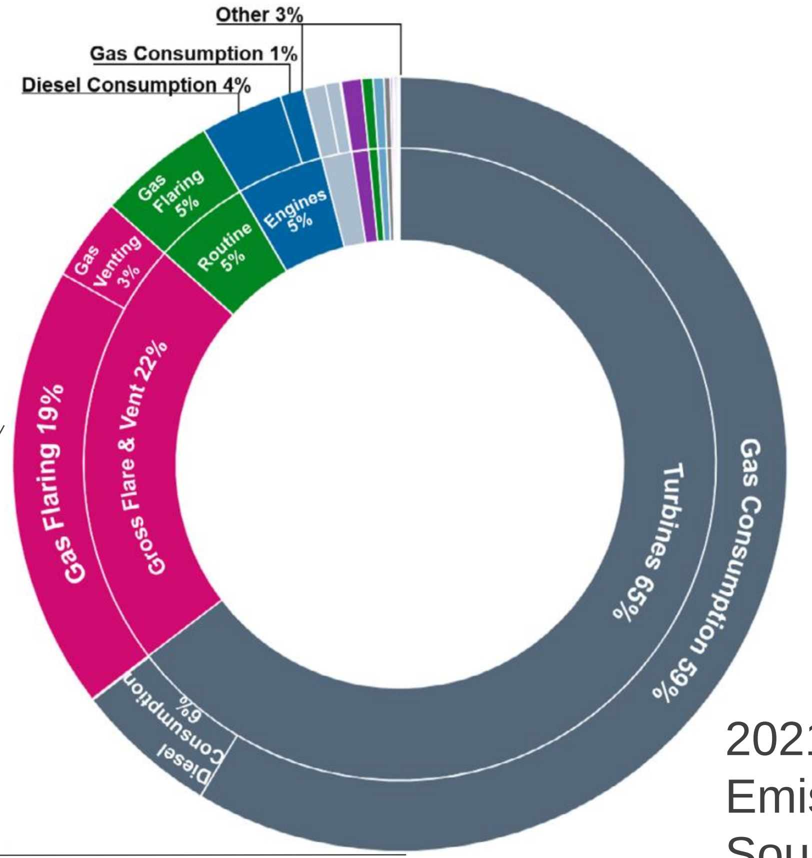
Overview

- In the early phases of project development, there is greater opportunity to prioritise emissions performance in the design basis
- Traditional approaches optimise for value drivers such as:
  - Cost
  - Reliability
  - Safety
- Emissions performance is now a more significant value driver to consider
- ERCE and Petrofac have recently carried out emissions performance assessment within a new FPSO development project

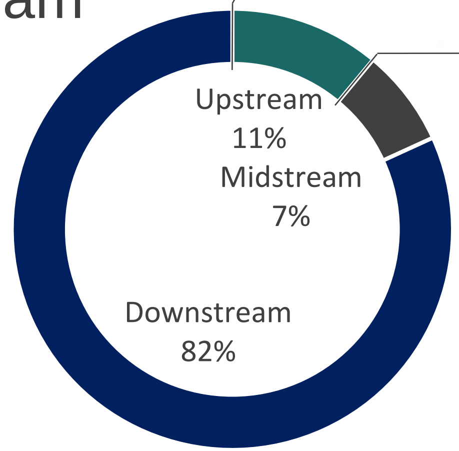


Upstream Industry Emissions

- The upstream industry emissions profile is dominated by product usage (Scope 3) emissions
- These cannot be addressed within the scope of upstream emissions reductions
- There are, however, significant achievable reductions in upstream scope 1 emissions



2021 Facility Emissions by Source and Category
Source: EEMS



UK Forties Blend Lifecycle Emissions Estimate
Source: Carnegie Endowment for International Peace

Emissions Performance Assessment

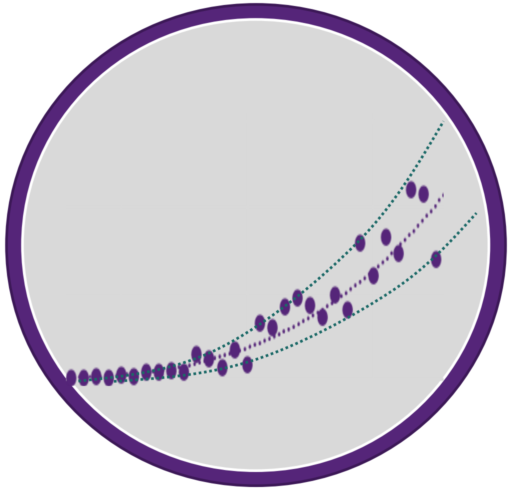
Emissions Performance Assessment

- There are a range of approaches which ERCE can deploy:

Benchmarking

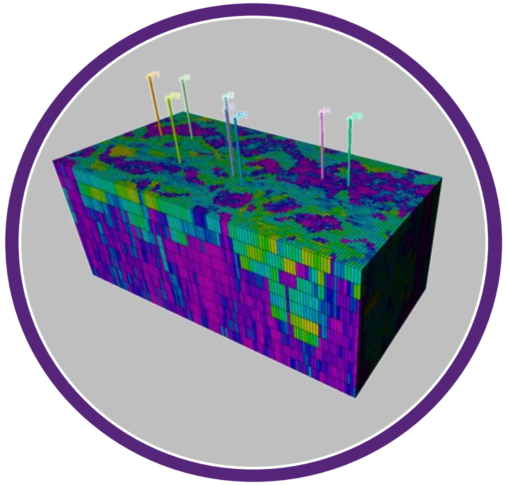
Analysis of extensive historical databases

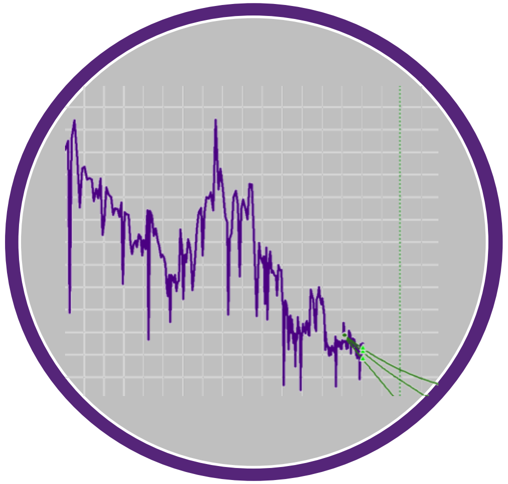
Empirical Analysis and Modelling



Modelling based on historical data

Deterministic Analysis and Modelling





Modelling based on first principles engineering

Benchmarking

- ERCE maintains a North Sea database of emissions data held alongside production data, categorised by field and facility, built from a combination of multiple publicly-available data sources

- Our database has the capability to benchmark CO_2e emissions against a variety of different reservoir and field performance metrics
  - Production to date
  - Field Recovery factor
  - Estimated Ultimate Recovery

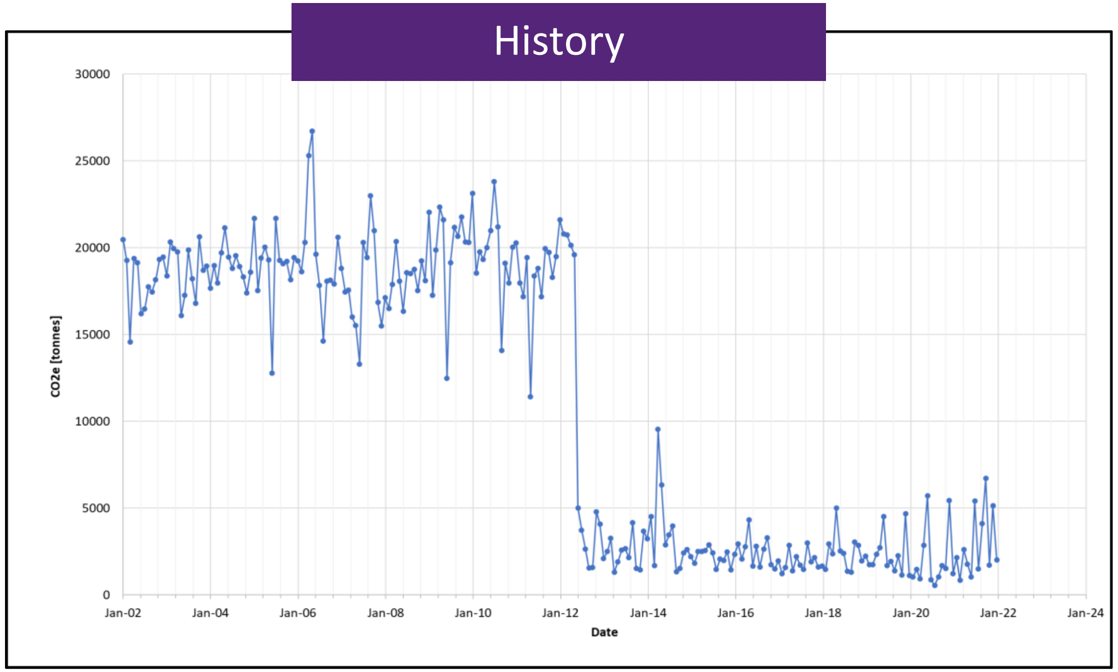
- ERCE can differentiate between Field, Field Type, Installation and Company

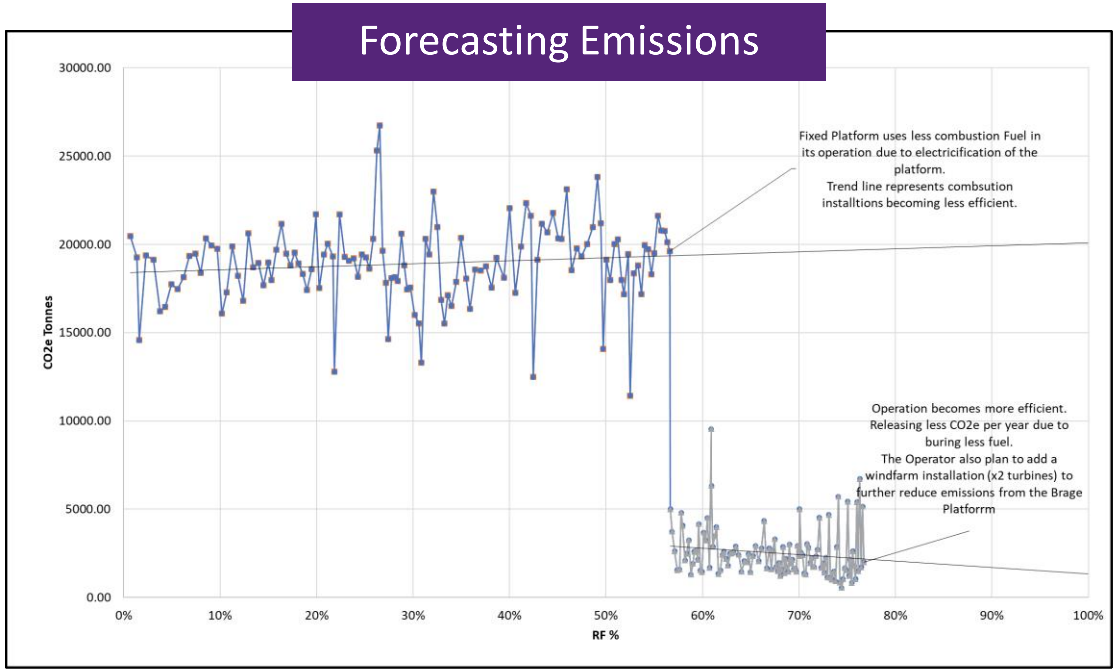
- Our analysis can also give a good approximation of emissions generated from installations outside of the North Sea. Derived from:
  - Production and Production Forecasting
  - Emissions sources and combustion types
  - Scale and Size

Name	Installation Type	Operation	FIELD, FIELDS or LOCATION	Field Type	Production Start Date Year	FIELD OPERATOR (MAJORITY)	OPERATING WATER DEPTH (M)	COUNTRY
Armada	Fixed	Processing Platform	Gaupe	Oil and Gas	2012	Norske Shell	90m	Norway
Brage	Fixed	Wellhead Platform	Brage	Oil	1993	Wintershall Dea, OKEA	140m	Norway
Brønn hode (Ringhorne)	Fixed	Wellhead Platform	Ringhorne	Oil and Gas	1999	Var Energi	130m	Norway
Draugen A	Fixed	Wellhead and Processing Platform	Draugen	Oil	1984	Norske Shell	250m	Norway
Draupner E	Fixed	Housing Platform	Draupner	Gas	1985	Equinor	70m	Norway
Draupner S	Fixed	Wellhead Platform	Draupner	Gas	1985	Equinor	70m	Norway
Edvard Grieg	Fixed	Wellhead and Processing Platform	Solveig	Oil	2021	Aker BP	100m	Norway
Ekofisk 2/4 J	Fixed	Main Processing Platform	Ekofisk	Oil and Gas	1969	Conoco Phillips Skandinavia AS	70m	Norway
Ekofisk 2/4 L	Fixed	Housing Platform	Ekofisk	Oil and Gas	1969	Conoco Phillips Skandinavia AS	70m	Norway
Ekofisk 2/4 M	Fixed	Wellhead and Processing Platform	Ekofisk	Oil and Gas	1969	Conoco Phillips Skandinavia AS	70m	Norway
Ekofisk 2/4 X	Fixed	Wellhead Platform	Ekofisk	Oil and Gas	1969	Conoco Phillips Skandinavia AS	70m	Norway
Ekofisk 2/4 Z	Fixed	Wellhead Platform	Ekofisk	Oil and Gas	1969	Conoco Phillips Skandinavia AS	70m	Norway
Eldfisk 2/7 A	Fixed	Wellhead Platform	Eldfisk	Oil and Gas	1979	Conoco Phillips Skandinavia AS	70m	Norway
Eldfisk 2/7 B	Fixed	Integrated Platform (Wellhead/Process/Housing)	Eldfisk	Oil and Gas	1979	Conoco Phillips Skandinavia AS	70m	Norway
Eldfisk 2/7 FTP	Fixed	Support Platform	Eldfisk	Oil and Gas	1979	Conoco Phillips Skandinavia AS	70m	Norway
Eldfisk 2/7 S	Fixed	Integrated Platform (Wellhead/Process/Housing)	Eldfisk	Oil and Gas	1979	Conoco Phillips Skandinavia AS	70m	Norway
Embla Feltet 2/7 D	Fixed	Wellhead Platform	Embla	Oil and Gas	1993	Conoco Phillips Skandinavia AS	70m	Norway
Gina Krog	Fixed	Integrated Platform (Wellhead/Process/Housing)	Gina Krog	Oil and Gas	2017	Equinor	120m	Norway
Grane	Fixed	Integrated Platform (Wellhead/Process/Housing)	Grane	Oil	2003	Equinor	130m	Norway
Gudrun	Fixed	Integrated Platform (Wellhead/Process/Housing)	Gudrun	Gas and Condensate	1975	Equinor	110m	Norway
Gulfaks A	Fixed	Integrated Platform (Wellhead/Process/Housing)	Gulfaks	Oil and Gas	1978	Equinor	220m	Norway
Gulfaks B	Fixed	Integrated Platform (Wellhead/Process/Housing)	Gulfaks	Oil and Gas	1978	Equinor	220m	Norway
Gulfaks C	Fixed	Integrated Platform (Wellhead/Process/Housing)	Gulfaks	Oil and Gas	1978	Equinor	220m	Norway
Heimdal	Fixed	Processing Platform	Heimdal	Gas and Condensate	1986	Equinor	120m	Norway
Huldra	Fixed	Integrated Platform (Wellhead/Process/Housing)	Huldra	Oil and Gas	2001	Equinor	185m	Norway
Ivar Aasen	Fixed	Wellhead Platform	Ivar Aasen	Oil and Gas	2008	Aker BP	110m	Norway
Johan Sverdrup	Fixed	Integrated Platform (Wellhead/Process/Housing)	Johan Sverdrup	Oil	2019	Equinor	115m	Norway
Kvitebjørn	Fixed	Wellhead and Processing Platform	Kvitebjørn	Oil	2004	Equinor	190m	Norway
Martin Linge A	Fixed	Wellhead and Processing Platform	Martin Linge	Oil and Gas	2021	Equinor	115m	Norway
Oseberg A	Fixed	Housing Platform	Oseberg	Oil and Gas	1998	Equinor	100m	Norway
Oseberg B	Fixed	Wellhead and Processing Platform	Oseberg	Oil and Gas	1998	Equinor	100m	Norway
Oseberg D	Fixed	Processing Platform	Oseberg	Oil and Gas	1998	Equinor	100m	Norway
Oseberg H	Fixed	Wellhead Platform	Oseberg	Oil and Gas	1998	Equinor	100m	Norway
Sleipner A	Fixed	Integrated Platform (Wellhead/Process/Housing)	nge and Sleipr	Gas and Condensate	1993	Equinor	83m	Norway
Sleipner B	Fixed	Riser	nge and Sleipr	Gas and Condensate	1993	Equinor	83m	Norway
Sleipner B	Fixed	Wellhead Platform	nge and Sleipr	Gas and Condensate	1993	Equinor	83m	Norway
Sleipner T	Fixed	Processing Platform	nge and Sleipr	Gas and Condensate	1993	Equinor	83m	Norway
Strafjord C	Fixed	Wellhead and Processing Platform	Stratfjord	Oil	1979	Equinor	150m	Norway
Stratfjord A	Fixed	Wellhead and Processing Platform	Stratfjord	Oil	1979	Equinor	150m	Norway
Stratfjord B	Fixed	Wellhead and Processing Platform	Stratfjord	Oil	1979	Equinor	150m	Norway
Tambar - ULA	Fixed	Integrated Platform (Wellhead/Process/Housing)	Ula	Oil and Gas	2019	Aker BP	70m	Norway
Tor 2/4 E	Fixed	Integrated Platform (Wellhead/Process/Housing)	Tor	Oil and Gas	1975	Conoco Phillips Skandinavia AS	70m	Norway
Troll A	Fixed	Integrated Platform (Wellhead/Process/Housing)	Troll	Gas	1995	Equinor	330m	Norway
Troll B	Fixed	Integrated Platform (Wellhead/Process/Housing)	Troll	Gas	1995	Equinor	330m	Norway
Valhal	Fixed	Integrated Platform (Wellhead/Process/Housing)	Valhal	Oil and Gas	1982	Aker BP	70m	Norway

Benchmarking Database

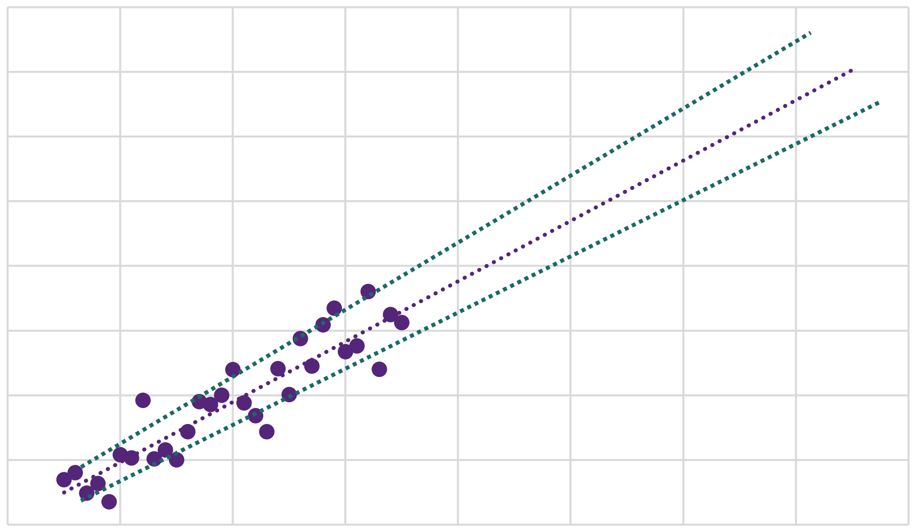
- Currently covers UKCS and Norwegian North Sea
    - 177 Fixed Platforms
    - 35 FPSOs
    - 191 UKCS offshore fields
    - 81 Norwegian offshore fields
- UKCS emissions data covering 2006 to latest reporting release
- Norwegian North Sea emissions covering 2002 to latest reporting release
- Example of utility reconfiguration

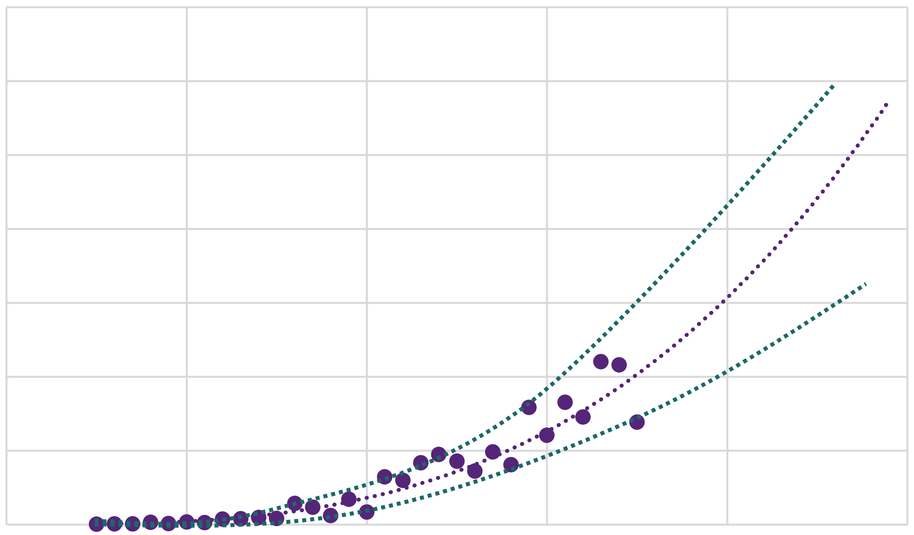




Emissions Performance Assessment

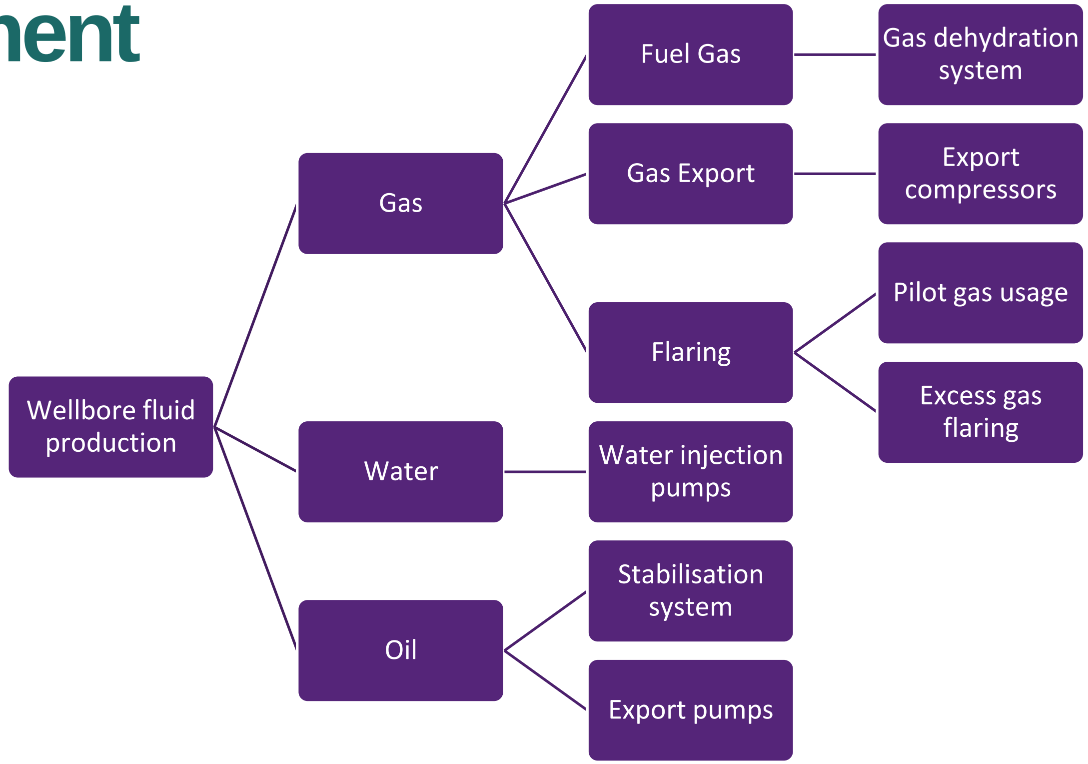
- Empirical Analysis
  - Historical emissions data, combined with other data such as oil/gas production, water production, water injection, can be used to categorise basic trends
  - This enables basic forecasting, and can also be used to tune deterministic models

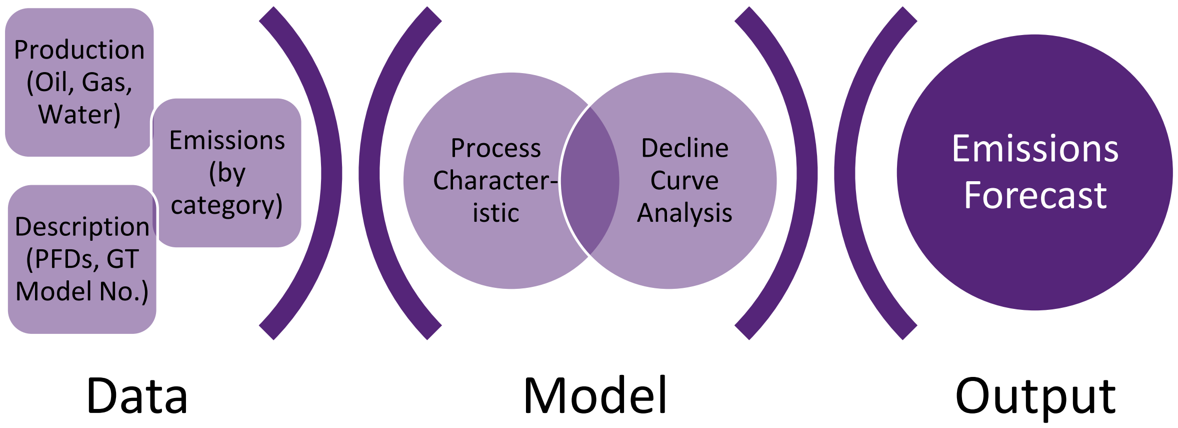




Emissions Performance Assessment

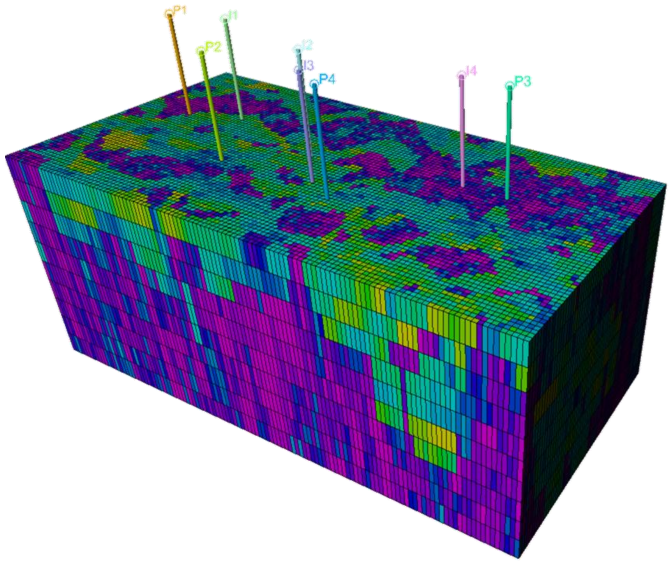
- Empirical Analysis
  - Example – a fixed platform produces crude oil from a mature field with stable GOR and steadily increasing WOR.
    - **What will the profile of the next 10 years' emissions look like?**
  - Historical production and emissions data are available
  - Process characteristic model is constructed:
    - A simple model of utility consumption can be constructed from limited design information (see right)
    - Model is then fitted to historical data to produce a set of characteristic functions and logical rules:
    - $Emissions = f(\dot{m}_{oil}) + f\left(\dot{m}_{water,produced}\right) + f\left(\dot{m}_{water,injected}\right) + f\left(\dot{m}_{gas}\right)$
  - Forecasts of oil production, GOR and WOR are constructed using DCA
  - A forecast of emissions can be produced in this way with limited input data and resources, but with crucial limitations:
    - Cannot fully model the off-design, operability or capacity constraints of process and utility systems
    - May not capture interdependence with other fields and facilities
    - DCA may not realistically reflect step changes in reservoir behaviour



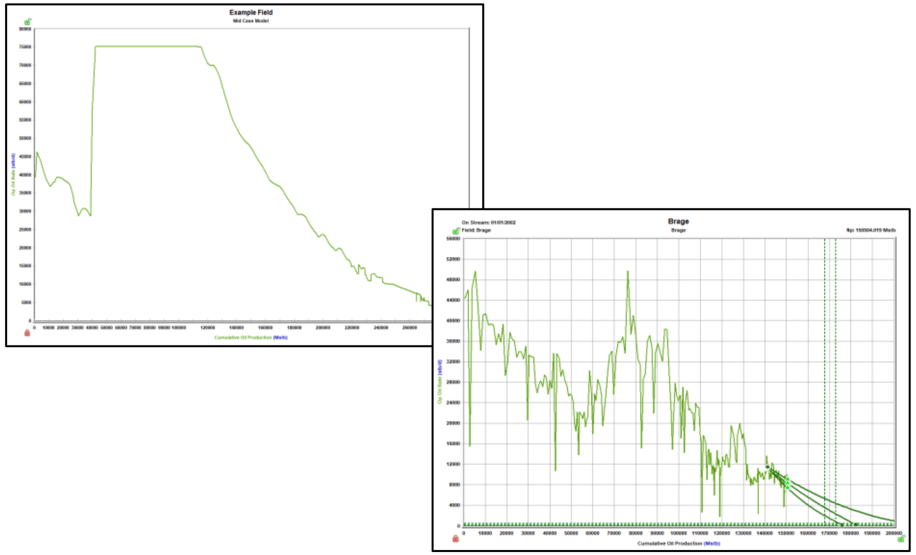


Emissions Performance Assessment

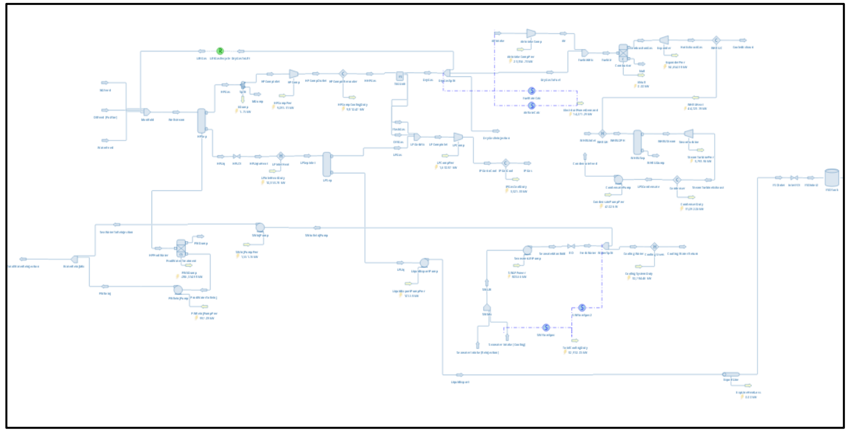
- Deterministic Analysis
  - First-principles analysis of a production process can enable more nuanced prediction and comparison of emissions under a variety of scenarios
  - ERCE’s subsurface expertise strongly contributes to this analysis
  - Generic process models can be applied using assumptions appropriate to the development type and region, or models can be tailored to the exact nature of the field and facility



Reservoir Dynamic Modelling



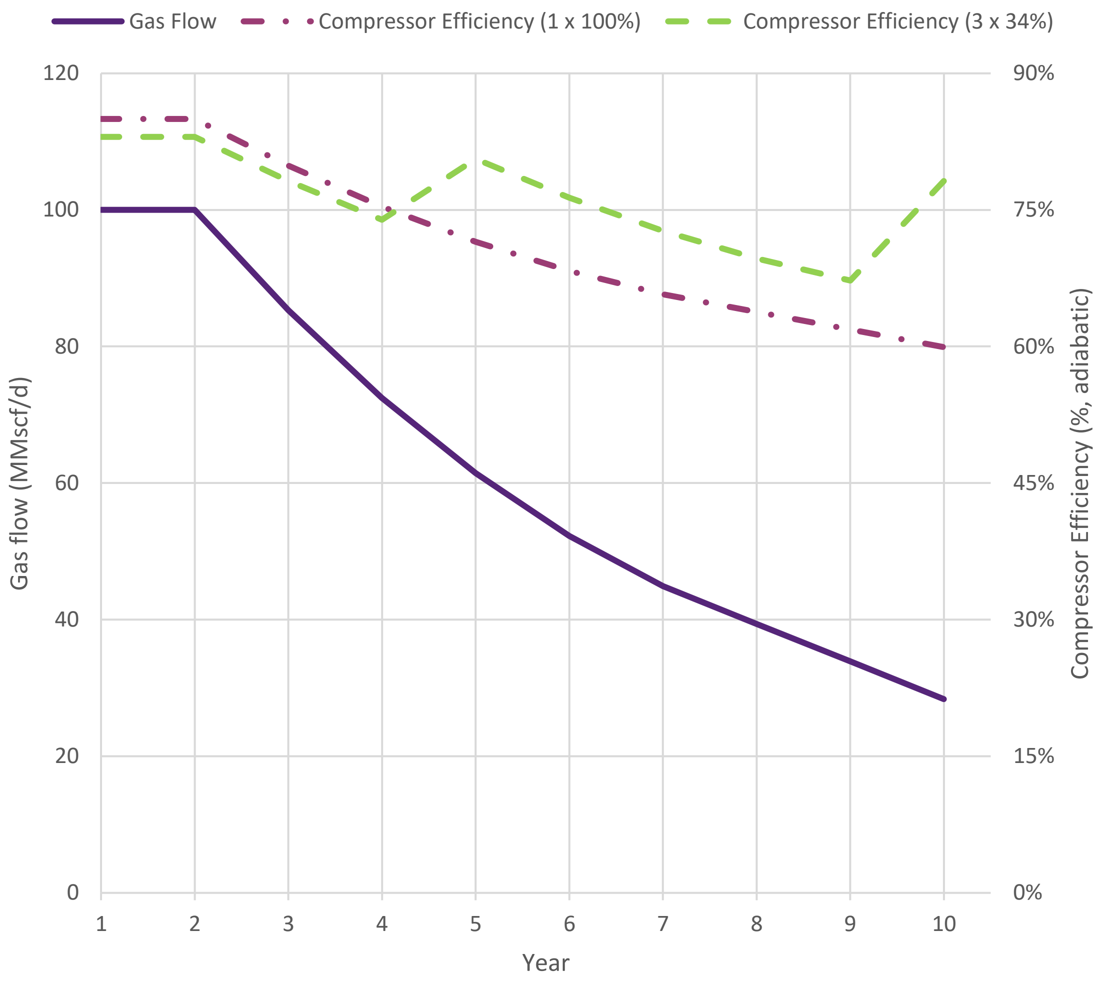
Reservoir Performance Modelling and Production Forecasting



Process / Utility System Modelling

Emissions Performance Assessment

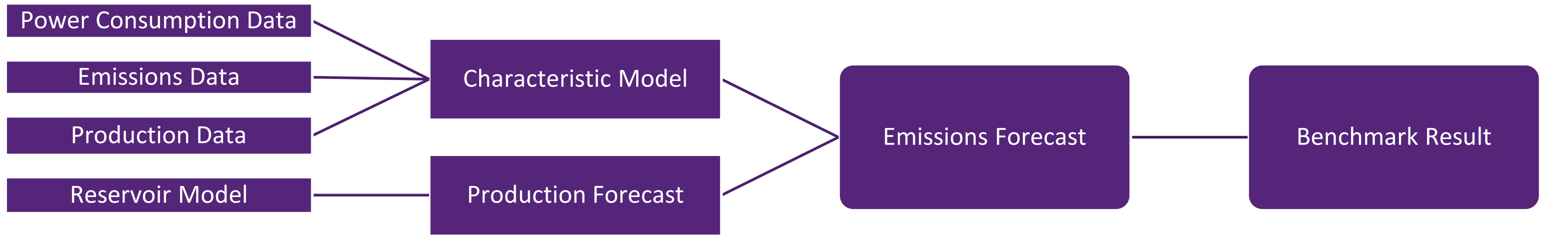
- Deterministic Modelling
  - Example – what is the potential emissions impact of reconfiguring a gas compression system from 1x100% to 3x34%?
  - The following data are available:
    - Gas composition
    - Gas volume profile
    - Compressor efficiency maps
  - Compressor performance is modelled for each year in both cases using Peng-Robinson EoS
  - Over a 10-year lifecycle, a 3.6% reduction in energy usage is achieved in this scenario
  - The optimal selection would also depend on the relative space, weight and CAPEX requirements of each configuration

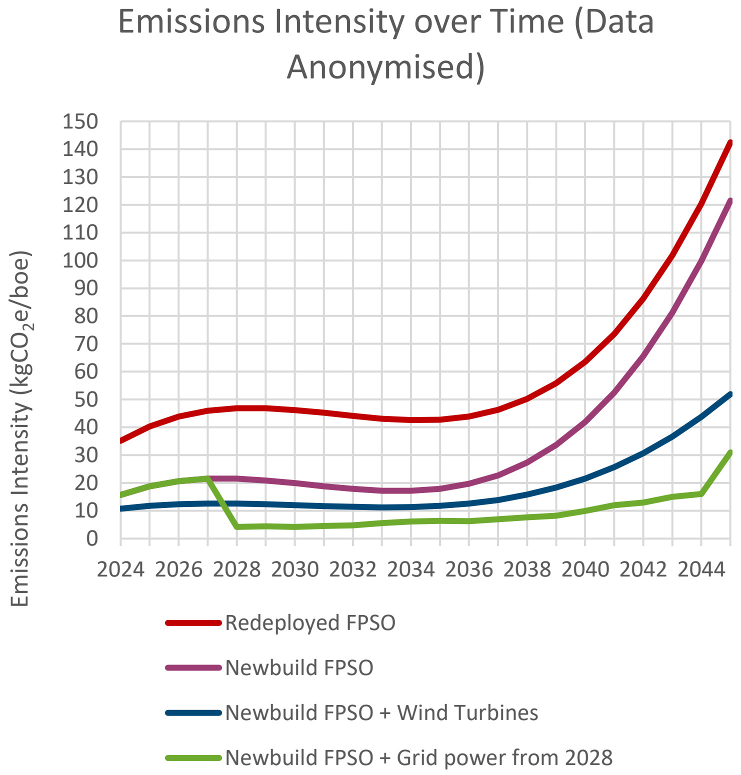


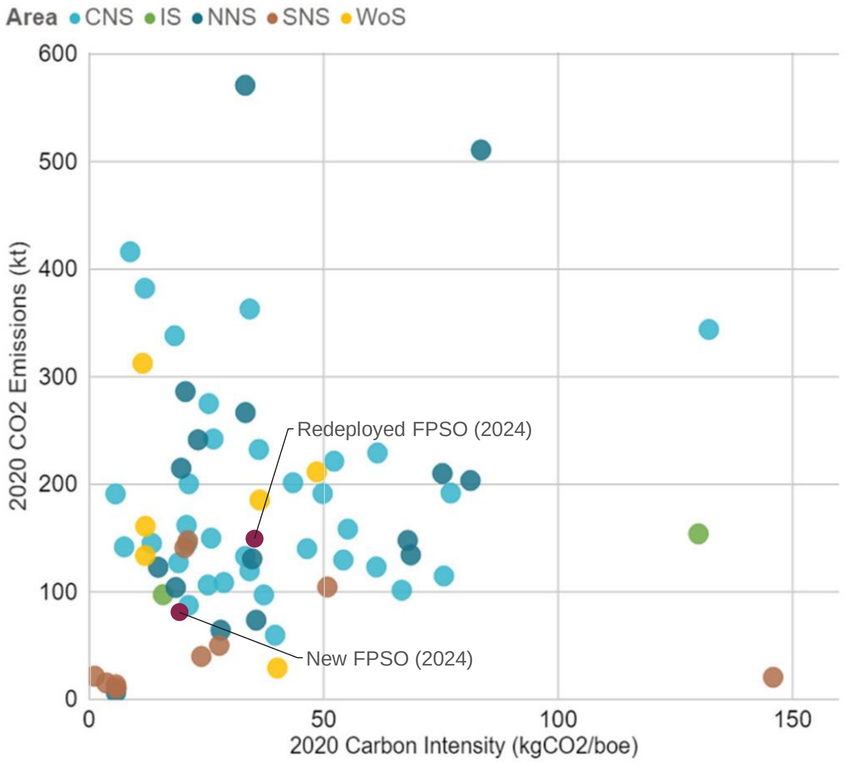
Case Example

Case Example – Field Development Emissions Forecast

- ERCE carried out reservoir modelling and emissions forecasting for a field development project
- A set of characteristic functions was developed to model the performance of an available (existing) candidate FPSO, with limited information
- This was compared against the forecast emissions for a selection of newbuild process and utility configurations developed by Petrofac
- Benchmarking provides important context, showing the ‘achievable’ emissions compared to analogue fields / facilities of similar type





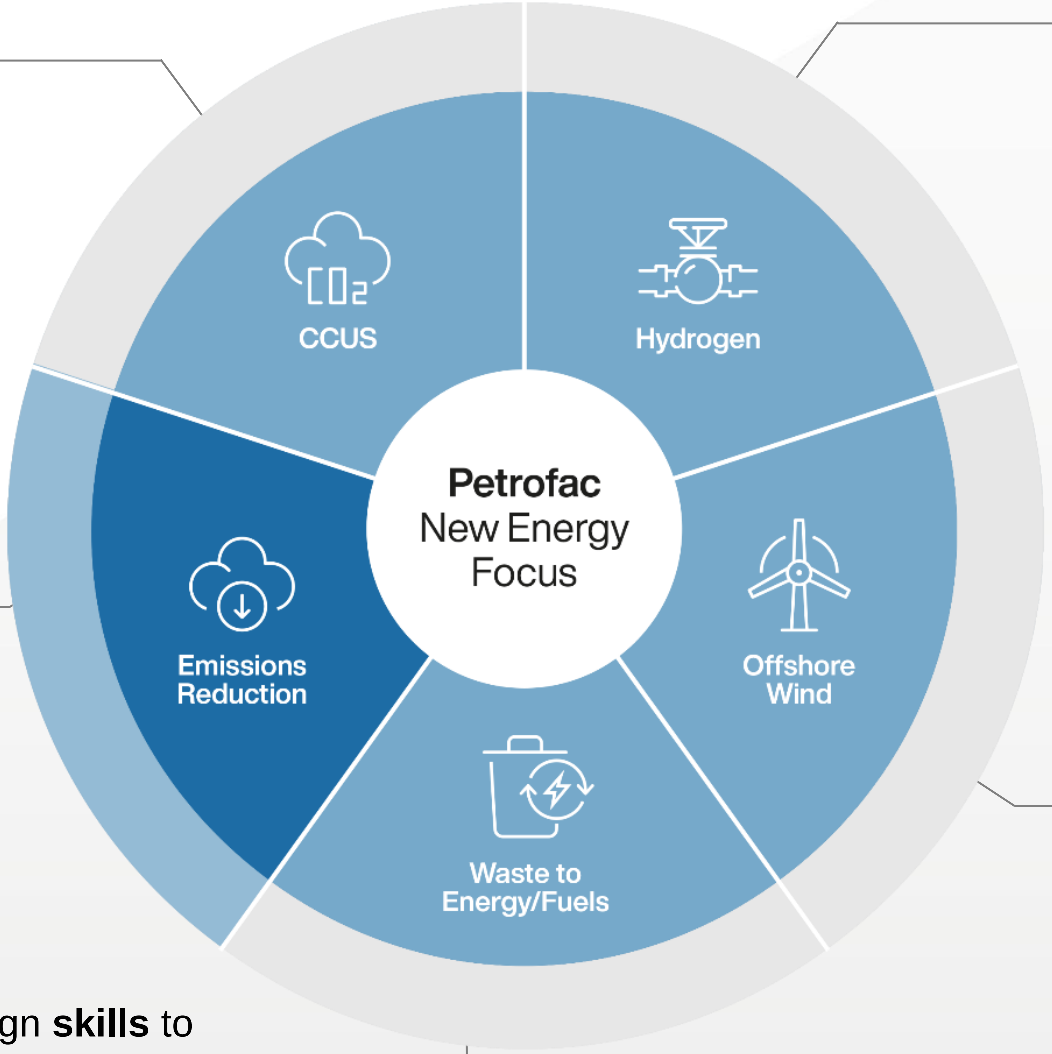


Petrofac Scope of Work

Capabilities to unlock value in New Energies

Using our expertise in **gas processing**, transport and storage to safely and economically **capture** and **store carbon**

Our **wind**, **solar** and **gas** capabilities allow us to design and build **green** hydrogen projects. Our **hydrocarbons experience** enables us to deliver large-scale **blue** hydrogen solutions



Leveraging our years of **experience** in **designing** and **operating** oil and gas assets, we support **in reducing** the **carbon intensity** of operations

Over 10 years' of **expertise** in **designing** and operating **offshore** electrical substations, both **HVAC** and **HVDC**

Using our **petrochemical** design **skills** to transform **waste feedstocks** into valuable products: road and sustainable aviation fuels

PETROFAC SCOPE OF WORK

- Baseline Power requirements and GHG emissions (for design life) calculated for converted vessel and new FPSO design (current without further emissions reduction improvements)
- Initial framing workshop to prepare long list of GHG reduction measures to be evaluated, including electrification options
- Assess each option in terms of weighted value drivers
- Prepare initial presentation ranking options (by grouping)
- Workshop with Client, and other stakeholders to go through options and shortlist for next phase
- Repeat power requirements and GHG emissions for selected emission abatement technology
- Prepare Final Report highlighting emissions reduction (existing FPSO, design at the beginning of this study, final design to be carried forward to next project phase)
- Revise model inputs to assess impact as design develops and new project information becomes available

BRAINSTORMING WORKSHOP: OPPORTUNITY STATEMENT

"There is an opportunity to demonstrate the FPSO design to be an exemplar for the offshore oil and gas sector for GHG emissions minimisation. We will evaluate a range of emissions reductions measures that could be deployed and select those that represent the best emissions reduction-value trade-off for the project."

EMISSIONS INTENSITY OPTION SCREENING CRITERIA

CRITERION	RELATIVE WEIGHTING
CAPEX	25%
OPEX	15%
GHG EMISSIONS REDUCTION	25%
SAFETY	20%
EASE OF INTEGRATION	15%
REGULATORY COMPLIANCE	TRAFFIC LIGHT
TECHNICAL MATURITY	TRAFFIC LIGHT

POWER SUPPLY/GENERATION – OPTIONS CONSIDERED

SI	OPTION	DESCRIPTION
A	Base Case 1 - New Hull + 5 x 25% (N+1) Dual Fuel Engines	5 x Wartsila 16V34DF (7.37MWe each)
B	Base Case 2 – Existing Hull Diesel engines converted to dual fuel	6 x MAN 16V32/40 converted to Dual Fuel engines
C	Converted Engines to start + Future Power from Shore	Converted engines until area-based electrification project green energy is available. High voltage power cable from nearest substation (assumed within 12km)
D	New Gas Engines to start + Future Power from Shore	As above with new DF engines to start
E	Converted Engines + Offshore Wind (3 turbines)	3 x 11MW turbines with converted engines supplying any shortfall during low wind/no wind periods. With battery system to allow time to start engines as required
F	New Gas Engines + Offshore Wind (3 turbines)	As above with new DF engines supplying any shortfall during low wind/no wind periods.
G	Converted Engines + Leased Offshore Wind (1 turbine)	1 x 14MW turbine with converted engines supplying any shortfall during low wind/no wind periods. Leased and O&M contract
H	GTGs with WHRUs	2 x 100% Gas Turbine Generators (Siemens SGT 750) with Waste Heat Recovery units

GHG EMISSIONS REDUCTION

SI	OPTION	% REDUCTION FROM BASE CASE LIFETIME EMISSIONS
A	Base Case 1 - New Hull + 5 x 25% (N+1) Dual Fuel Engines	
B	Base Case 2 – Existing Hull Diesel engines converted to dual fuel	
C	Converted Engines to start + Future Power from Shore	67
D	New Gas Engines to start + Future Power from Shore	67
E	Converted Engines + Offshore Wind (3 turbines)	53
F	New Gas Engines + Offshore Wind (3 turbines)	53
G	Converted Engines + Leased Offshore Wind (1 turbine)	23
H	GTGs with WHRUs	-3

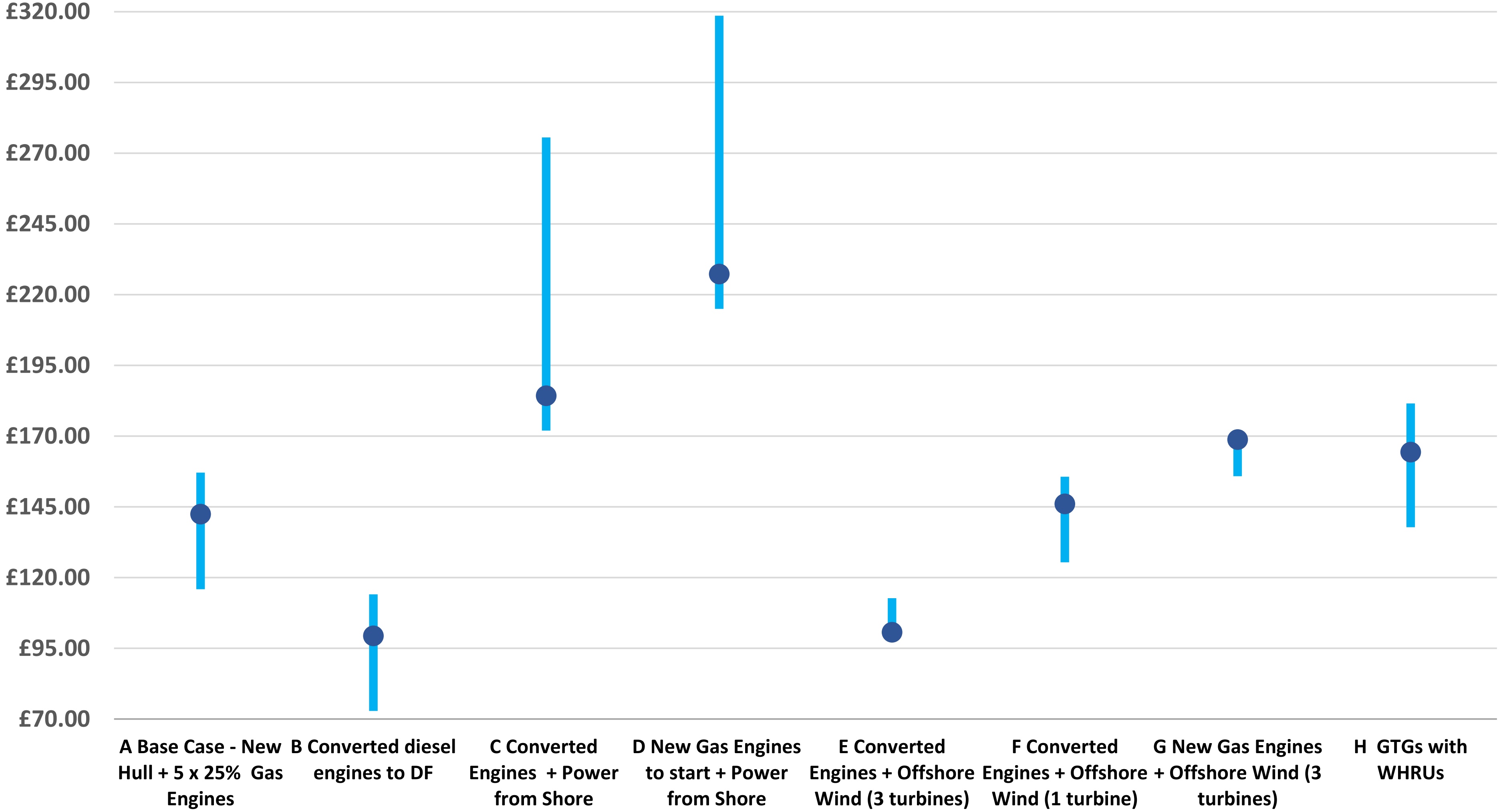
CONCEPT RANKING WEIGHTED SUM RESULTS

SI	CONCEPT RANKING & WEIGHTED SUM	GHG EMISSIONS REDUCTION	CAPEX	OPEX	SAFETY	EASE OF INTEGRATION	WEIGHTED SUM	RANK
	CRITERIA'S RELATIVE VALUE %	25.00	25.00	15.00	20.00	15.00		
	ALTERNATIVES MATCH TO CRITERIA% 5 = BEST, 3 =AVG, 1 = WORST							
A	Base Case 1 - New Hull + 5 x 25% (N+1) Dual Fuel Engines	2	3	3	2	5	285	7
B	Base Case 2 – Existing Hull Diesel engines converted to dual fuel	2	5	3	2	4	320	3
C	Converted Engines to start + Future Power from Shore	5	3	1	4	2	325	2
D	New Gas Engines to start + Future Power from Shore	5	2	1	4	2	300	5
E	Converted Engines + Offshore Wind (3 turbines)	4	3	5	3	3	355	1
F	New Gas Engines + Offshore Wind (3 turbines)	4	1	5	3	3	305	4
G	Converted Engines + Leased Offshore Wind (1 turbine)	3	4	1	3	3	295	6
H	GTGs with WHRUs	1	3	2	3	4	250	8

CONCEPT RANKING SENSITIVITY RESULTS

SI	OPTION	Agreed Weighting	Equal Weighting	>GHG Weighting
A	Base Case 1 - New Hull + 5 x 25% (N+1) Dual Fuel Engines	7	4	7
B	Base Case 2 – Exisiting Hull Diesel engines converted to dual fuel	3	2	5
C	Converted Engines to start + Future Power from Shore	2	4	2
D	New Gas Engines to start + Future Power from Shore	5	6	4
E	Converted Engines + Offshore Wind (3 turbines)	1	1	1
F	New Gas Engines + Offshore Wind (3 turbines)	4	2	3
G	Converted Engines + Leased Offshore Wind (1 turbine)	6	6	6
H	GTGs with WHRUs	8	8	8

LEVELISED COST OF ENERGY (£/MWH)



STUDY OUTCOMES

- Option E (dedicated, owned, wind turbines + local generation using converted dual-fuel engines) top
- Results in >50% reduction in GHG emissions from base with moderate capital intensity and low OPEX impact
- Next best option is C (Power from shore + local generation using converted dual-fuel engines)
- Maximum GHG reduction, risk of misalignment/lack of control
- Recommended concept taken forward to next phase: dual-fuel converted engines, with the ability to import external power via a HV slip ring within the swivel
- The nature of the power import will be determined at a future stage in the project

- **Petrofac and ERCE worked together to evaluate the emissions and value impact of design options for an FPSO development**
- **A combination of approaches was taken to develop a full picture, encompassing the modelling of subsurface and facility characteristics**
- **Emissions intensity was prioritised as a significant project value driver at an early development stage**
- **Decision-makers were given the benefit of thorough analysis of the trade-offs between emissions reduction and value impact**