Independent Assessment of the European Commission's Fuel Quality Directive's "Conventional" Default Value

Final Report

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Abbreviations and Acronyms

C2H6	ethane
CARB	California Air Resources Board
CH4	methane
CO2	carbon dioxide
CO2E	carbon dioxide equivalent
CONCAWE	Conservation of Clean Air and Water in Europe
EC	European Commission
EIA	United States Energy Information Administration
EU	European Union
EUCAR	European Council for Automotive Research and Development
FCC	Fluid Catalytic Cracker
FQD	Fuel Quality Directive
GHG	Greenhouse Gas
GOR	Gas-Oil Ratio
HFO	Heavy Fuel Oil
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IOC	International Oil Company
ISO	International Organization for Standardization
JEC	JRC, EUCAR and CONCAWE
JRC	European Commission Joint Research Centre
LBST	Ludwig-Bölkow-Systemtechnik GmbH
LCA	Lifecycle Analysis
LCFS	Low Carbon Fuel Standard
MCON	Marketable Crude Oil Name
NETL	National Energy Technology Laboratory
NOAA	National Oceanic and Atmospheric Administration
NOx	Oxides of Nitrogen
OGP	Oil and Gas Producers
OPGEE	Oil Production Greenhouse Gas Emissions Estimator
SPDC	Shell Petroleum Development Company
TTW	Tank-To-Wheel
ULCC	Ultra Large Crude Carrier
VFF	Venting, Flaring and Fugitives
VLCC	Very Large Crude Carrier
WOR	Water-Oil Ratio
WTT	Well-To-Tank
WTW	Well-To-Wheels

Executive Summary

The European Union's (EU) Fuel Quality Directive (FQD) aims to reduce the greenhouse gas (GHG) intensity of fuel supplied in the EU for use in road vehicles and non-road mobile machinery. To achieve this, the FQD introduces an obligation on fuel suppliers to reduce the GHG intensity of the fuels they supply by six (6) percent by 2020, compared to a 2010 baseline intensity. The draft implementing measure for Article 7a (5)(a) of the FQD (EC 2011) would require gasoline and diesel suppliers to use default GHG intensity values that distinguish between three main categories of "feedstock": conventional crude oil, oil shale, and natural bitumen. The proposed conventional crude default values for gasoline and diesel were based on an analysis by the JEC (a consortium of the European Commission Joint Research Centre (JRC), the European Council for Automotive Research and Development (EUCAR), and the Conservation of Clean Air and Water in Europe (CONCAWE)) and the values proposed for natural bitumen were based on analysis for the European Commission (EC) by Adam Brandt.

The objective of this study was two-fold: 1) analyse the methodology that has been used in the JEC reports (JEC v3c and v4) to determine the default conventional crude oil gasoline and diesel GHG intensity values; and 2) using that improved understanding, develop a more accurate default GHG intensity range for gasoline and diesel from conventional crude oils. This study had a seven (7) week timeline commencing on August 22, 2013 and a final deliverable date of October 9, 2013.

The JEC reports (JEC v3c and v4) include lifecycle analyses (LCA) that determine GHG intensities for gasoline and diesel. The LCA stages reviewed in this study were: 1) crude oil production; 2) venting, flaring, and fugitives; 3) crude oil transport; and 4) refining. The final LCA stages of finished product transport and combustion are not analysed, as there is general consensus in the scientific community on carbon intensity for these stages.[1] Data quality and availability are two of the most important factors in LCAs. Worldwide crude oil LCAs, including those performed in the JEC reports, need to make critical assumptions due to limited acceptable data outside of Canada and the USA. While these limitations prevent the determination of the exact GHG intensities for gasoline and diesel, improvements, including the most up-to-date data and models and a consistent LCA methodology, can increase an LCA's accuracy.

ICF determined three most likely ranges for gasoline and diesel GHG intensities using the Oil Production Greenhouse Gas Emissions Estimator (OPGEE_v1.0) and the Jacobs Study (Jacobs 2012) for crude oil production, venting, flaring, and fugitives, and crude oil transport. These ranges are identified as *OPGEE Only*, *Jacobs Only,* and *OPGEE + Jacobs*. The CONCAWE study (CONCAWE 2007) was used to develop a most likely range for refining. Figure 1 below shows the most likely ranges for the LCA stages analysed and their corresponding JEC values.

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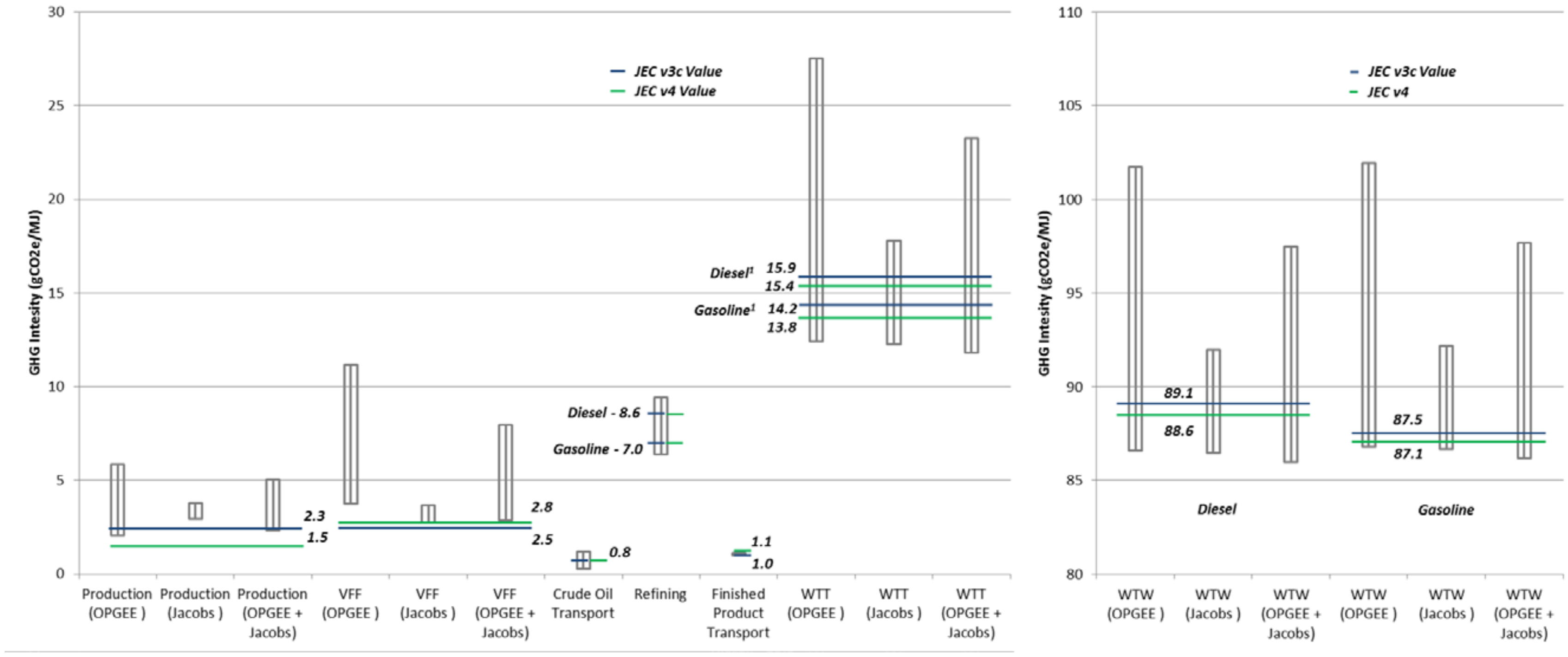
[1] Greenhouse Gas Regulated Energy and Emissions Tool (GREET) Model developed by Argonne National Laboratory, JEC v3c and v4.

Figure 1. Comparison of JEC Report and the Estimated Most Likely Range



Note: 1 – JEC individual stages are not additive to the WTT value due to crude energy loss during the refining stage

The following are key elements of the analysis:

Overall

- GHG intensities of conventional crude oils fall on a continuum, not just one value, and some light and heavy conventional crudes have GHG intensities that are similar or even higher than those of crudes derived from natural bitumen. The results of the study do not support the current FQD categorization of feedstock by conventional, natural bitumen and oil shale crude oils.
- Gasoline and diesel GHG intensities from conventional crude oil fall within a very large spectrum shown by the estimated most likely ranges. The estimated diesel ranges for the three sets of data are 86.6–101.7 gCO2/MJ (OPGEE), 86.5-92.0 gCO2e/MJ (Jacobs), and 86.0-97.4 gCO2e/MJ (OPGEE + Jacobs). The estimated gasoline ranges for the three sets of data are 86.8–101.9 gCO2/MJ (OPGEE), 86.7-92.2 gCO2e/MJ (Jacobs), and 86.2-97.6 gCO2e/MJ (OPGEE + Jacobs). The ranges are due to data uncertainty and limited data availability and a variety of recovery techniques and flaring volumes and efficiencies. Differences of 3-4 gCO2e/MJ are equivalent to 50-75% of the 6% GHG intensity reduction standard.
- Given that the intent of the FQD is focused on average crude oil feedstocks supplied in the EU, the GHG intensity of conventional crude oil should focus on the **average** energy and emissions associated with crudes actually delivered to EU refineries. The JEC report uses a combination of average and marginal methodologies (i.e., the next barrel refined) to determine the marginal gasoline and diesel GHG intensity rather than the average intensity.
- The data sources and methodologies used in the JEC report to determine the gasoline and diesel GHG intensities from conventional crude oil are dated and do not fully represent the GHG intensity of current operations or the latest methodologies for estimating emissions.
- Data quality and availability are two of the most important factors in LCA estimations. There is limited high-quality data available for crude oils outside of Canada and the USA. For most other crudes, the LCA studies need to make many assumptions, leading to high uncertainty in comparing the crudes.
- Not distinguishing the GHG intensities of the different conventional crudes in the FQD could result in shifts to high GHG intensity crudes from countries such as Russia, Nigeria, or Venezuela, which would increase actual GHG emissions instead of reducing them.

Crude Oil Production

- Oil and Gas Producers (OGP) (OGP 2005 and 2011) is the main source of data for conventional crude oil production. The limitations of OGP data include: a) data are reported voluntarily by the industry and are not audited; b) data are aggregated at a country and regional level and not at a field- or crude-specific level; c) data are also aggregated as hydrocarbon production, including crude oil and natural gas; d) data coverage is limited (fewer than 50% of regions supplying crude to the EU report data); e) estimation methodologies employed by Member Companies used to report data are unclear; and, f) data are only representative of the companies reporting and is likely introducing sampling bias.

- The JEC report uses OGP data in regions with low data coverage and considers them representative of the entire region (e.g., over 37% of the crude refined in the EU originates from the Former Soviet Union region, which has only 4% data coverage). This increases the uncertainty of the LCA.

Venting, Flaring, and Fugitives

- Flaring and venting from oil production are the most important factors in uncertainty for LCA estimations.
- While NOAA data (National Oceanic and Atmospheric Administration) (NOAA 2011) were used to estimate flaring GHG intensities, the JEC report uses both oil and gas production as the denominator for flaring estimates. However, most, if not all, flaring happens in oil fields where infrastructure is insufficient to handle the associated gas. This underestimates the GHG intensity from flaring.
- The JEC report used OGP data for venting and fugitives, which lack the level of detail and specificity necessary to estimate the emissions.
- Ranges of uncertainty in the potential flaring efficiencies (90%-98%) for countries with significant flaring emissions (i.e., Russia, Cameroon, and Nigeria) suggest that the reported GHG intensities for these countries could be 3-7 gCO2e/MJ crude higher than the JEC reports.

Crude Oil Transport

- The JEC performed a marginal analysis for the GHG intensity from crude oil transport and determined the emissions from transporting heavy Middle East crude to Europe via the Cape of Good Hope.
- An average LCA approach that considers separate emissions from crude oil transport for each producer/reservoir and to each destination would result in a more accurate LCA. Crude oil transport GHG intensity can range from 0.3-2.1 gCO2e/MJ.

Refining

- The JEC uses a marginal analysis developed by CONCAWE for gasoline and diesel GHG intensity even though the FQD requires an average approach for calculating the GHG intensities.
- The CONCAWE refinery analysis uses a proprietary refinery model, which lacks transparency. Consequently, the results cannot be replicated or confirmed.

Recommendations to Improve the Accuracy of the GHG Intensity Values

- Due to the spectrum of crude oil GHG intensities, accurate LCA modeling needs to differentiate and evaluate GHG intensities for each crude oil individually (including natural bitumen and oil shale feedstock crude oils). The result of such modeling would be more representative of the actual gasoline and diesel GHG intensity.
- The most recent public, transparent, verifiable, and reproducible data and models (such as OPGEE) should be used to determine the individual crude oil GHG intensities. The data and models should

be able to determine crude oil specific (e.g., by Marketable Crude Oil Name (MCON) or field) GHG intensities.

- LCA modeling should determine the average gasoline and diesel GHG intensity for refining in 2010 using the EU 2010 set of crudes and total EU refining emissions and apply this value to all crude oil feedstocks. The chosen allocation or substitution methodology needs to be transparent.

1 Introduction

The European Union's (EU) Fuel Quality Directive (FQD) aims to reduce the greenhouse gas (GHG) intensity of fuel supplied in the EU for use in road vehicles and non-road mobile machinery. GHG intensity is measured as the amount of GHG emissions produced through the lifecycle of a transportation fuel per unit of energy. In the FQD the unit for GHG, intensity is grams of carbon dioxide equivalent per megajoule of fuel (gCO2e/MJ). To achieve this, the FQD introduces an obligation on fuel suppliers to reduce the GHG intensity of the fuels they supply by 6 percent by 2020, compared to a 2010 baseline intensity. The draft implementing measure for Article 7a (5)(a) of the FQD (EC 2011) would require gasoline and diesel suppliers to use default lifecycle GHG intensity values that distinguish between three main categories of feedstock shown in Table 1: conventional crude oil, oil shale, and natural bitumen.

Table 1. FQD Default GHG Intensities by Feedstock for Gasoline and Diesel

Feedstock	Gasoline GHG Intensity (gCO2e/MJ)	Diesel GHG Intensity (gCO2e/MJ)
Conventional Crude Oil	87.5	89.1
Natural Bitumen	107.0	108.5
Oil Shale	131.3	133.7

Per the draft FQD implementing measure (EC 2011), the gasoline and diesel GHG intensity values should be "based on the average default greenhouse gas intensity values". In the draft implementing measure, the proposed conventional crude default values for gasoline and diesel shown in Table 1 were based on analysis by JEC (JEC v3c).The values proposed for natural bitumen—107 gCO_2e/MJ gasoline and 108.5 gCO_2e/MJ diesel, which are 22% higher than the values for conventional crudes—were based on analysis for the Commission by Adam Brandt (Brandt 2011). A number of studies including those performed by NETL (National Energy Technology Laboratory) (NETL 2008), TIAX (TIAX 2009), both Jacobs reports (Jacobs 2009 and 2012), Brandt (Brandt 2011), ICCT ((International Council on Clean Transportation) , ICCT 2010) and OPGEE (OPGEE 2013), have shown that the GHG intensities of crude oils fall on a continuum and that some light and heavy "conventional" crudes have GHG intensities that are similar or higher than those of crudes derived from natural bitumen. The draft FQD implementing measure states that "it is clear from the study of oil sands[2] that there is an overlap in the greenhouse gas emissions of the worst performing conventional crude feedstocks… and the best performing natural bitumen feedstocks" (EC 2011). Nevertheless, in the current draft implementing measure, all feedstocks within the category of "conventional crudes" would be assigned only one GHG intensity default value, while natural bitumen and oil shale are currently identified as the higher GHG intensity feedstocks.

The objective of this study is two-fold: 1) to analyse the methodology that has been used in the JEC reports (JEC v3c and v4) and used in the FQD to determine the lifecycle GHG emissions intensity of "conventional crudes'; and 2) using that understanding, develop an estimate of the default GHG intensity range for "conventional" crude oils. The JEC v3c report published in 2011 produced the values used within the FQD

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[2] Brandt 2011, page 41

implementing measure and JEC v4 is an update to the v3c report published in 2013. This study had a seven (7) week timeline commencing on August 22, 2013 and a final deliverable date of October 9, 2013.

The JEC reports (JEC v3c and v4) include lifecycle analyses (LCA) that determine GHG intensities for gasoline and diesel. The LCA stages reviewed in this study were: 1) crude oil production; 2) venting, flaring, and fugitives; 3) crude oil transport; and 4) refining. The final LCA stages of finished product transport and combustion are not analysed, as there is general consensus in the scientific community on carbon intensity for these stages.[3] Data quality and availability are the most important factors in LCAs. Worldwide crude oil LCAs, including those performed in the JEC reports, need to make critical assumptions due to limited acceptable data. While these limitations prevent the determination of the exact GHG intensities for gasoline and diesel, improvements including the most up-to-date data and models and a consistent LCA methodology can increase an LCA's accuracy.

This report is structured as follows: Section 2 reviews and analyses the data sources and methodology used to determine the conventional crude default value; Section 3 assesses the rigour of the lifecycle analysis (LCA) performed by the JEC. Sections 4 and 5 compare the analysis performed for the European Union (EU) with other studies and present an estimated most likely range for the conventional crude default value.

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[3] Greenhouse Gas Regulated Energy and Emissions Tool (GREET) Model developed by Argonned National Laboratory, JEC v3c and v4.

2 Analysis of JEC Data Sources and Methodology

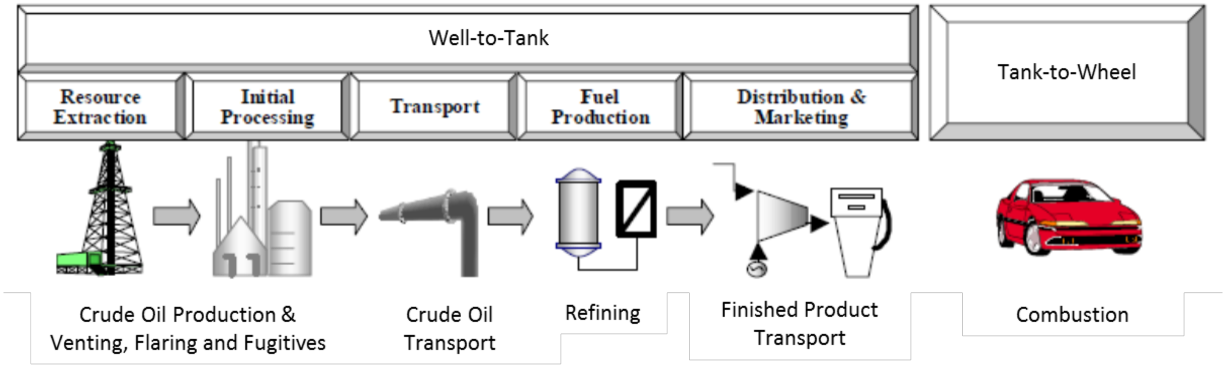
An effective LCA begins with identifying the intended purpose of the analysis. In the case of the FQD, the purpose was to establish the average GHG intensity of transport fuels (i.e., gasoline and diesel) consumed in the European Union. Second, key design elements must be identified prior to performing the LCA in order to ensure that data sources and methodology produce a result aligned with the intended purpose of the LCA. When data sources and methodology do not align with the key design elements, the resulting LCA cannot achieve its objective.

The analysis of JEC data sources and methodology has been broken up into the individual LCA stages: (1) Crude Oil Production, (2) Venting, Flaring, and Fugitives, (3) Crude Oil Transport, and (4) Refining. This report does not address finished product transport and combustion, as there is general consensus in the scientific community on carbon intensity for these stage.[4] Figure 2 below shows what is incorporated in the well-to-tank (WTT) and tank-to-wheel (TTW) portions (edited from CEC 2007) which combine for the well-to-wheels (WTW).

Marginal versus Average Lifecycle Analysis

In the context of conventional crude oil production, a marginal lifecycle analysis determines the GHG intensity of either the next increased or decreased unit of gasoline or diesel consumed or produced compared to current consumption or maximum production volumes. This includes looking at the marginal crude oil produced, transported and refined. An average lifecycle analysis determines the average GHG intensity of gasoline and diesel by taking into account the average crude oil produced, transported, and refined based upon a set crude slate. With the FQD's objective to set default values for the average gasoline and diesel GHG intensity, an average lifecycle analysis for gasoline and diesel is required.

Figure 2. WTT and TTW Portions of an LCA for Conventional Crude Oil to Gasoline and Diesel



The analysis will look at the following factors for each LCA stage to determine whether the overall LCA meets key design factors:

1. Key design elements of an LCA that would determine the average EU default GHG intensity values for gasoline and diesel
2. Data Sources of the JEC Report
3. Methodology of the JEC Report

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[4] Ibid.

Table 2 below lists the main data sources of both versions of JEC reports for the four identified LCA stages. Most of the data sources are not current and only five of the 11 were produced in the last eight years.

Table 2. Analysed JEC Data Sources

Data Sources Analysed	JEC v3c or v4	LCA Stage
OGP 2005	JEC v.3c	Crude Oil Production, VFF
OGP 2011	JEC v.4	Crude Oil Production, VFF
CONCAWE 2007	JEC v.3c and 4	Crude Oil Refining
TotalFinaElf, Shell	JEC v.3c and 4	Crude Oil Transport
GM 2002	JEC v.3c and 4	Crude Oil Transport
GEMIS 1999 and 2002	JEC v.3c and 4	Crude Oil Transport
SPDC 2001	JEC v.4	Crude Oil Transport
NOAA 2011	JEC v.3c and 4	VFF
IEA 2012	JEC v.3c and 4	Crude Oil Production, VFF
BP 2005	JEC v.3c and 4	Crude Oil Production, VFF
BP 2012	JEC v.3c and 4	Crude Oil Production, VFF

The set of critical elements listed in Table 3 and ICF's key LCA design parameters for each stage helped determine whether the data sources meet the standards of the LCA rigour required for this analysis.

Table 3. Description of Critical Data Elements

Critical Element	Brief Description
Reliability	Captures the overall consistency of the data. Considers factors such as data submissions (regulatory or voluntary); reporting entity (regulatory agency or trade association); level of data aggregation (regional or site specific); data derivation (estimates or first principles).
Accuracy	A gauge of how close the data are to a measure's actual or true value. In most cases, LCAs use reported data or measured data to determine or compute the desired measurement. As such, factors for consideration include representativeness of data sources for a given region or country and the methodology used to compute the data.
Vintage	Indicates the year in which data were provided. The scope of discussion relating to vintage include the comparison of similar studies to determine if more recent or relevant data exist based on updated data quality indicators. It is important to note that old data are not necessarily an indicator of poor vintage; rather, there is some overlap with reliability in the consideration of vintage.
Quality	Data quality includes multiple considerations and has some overlap with other critical elements. For the purposes of this analysis, it generally refers to the degree of excellence exhibited by the data in relation to the portrayal of an actual scenario. It includes factors such as reference to ISO 14040 and 14044 or other LCA standards, the extent to which data or data sources have been third-party audited, completeness, consistency, identified data gaps, public accessibility, and reproducibility.

Table 4 below identifies the important LCA methodological aspects that will be analysed to determine if they meet the standards of LCA rigour for determining the average EU default GHG intensity values for gasoline and diesel. LCA rigour was determined by comparing the data and methodologies of the JEC Report with the critical elements listed in Table 3 and ICF's key LCA design parameters.

Table 4. Important LCA Methodology Aspects

LCA Methodological Aspect	Description
LCA Boundaries	The boundaries of a given LCA describe which sources of GHG emissions are included in the study scope and which are excluded.
Inputs and Modeling Assumptions	Due to data access limitations and the complexity of and variation in the practices used to extract, process, refine and transport crude oil, LCA practitioners often use simplified assumptions to model recovery processes. A marginal or average approach must be determined prior to beginning the LCA.
Data Quality and Transparency	See Table 3, Description of Critical Data Elements.
Allocation, Co-Products, and Offsets	Allocation is a method used by LCA practitioners to attribute a portion of the emissions burden to co-products. Co-products are two or more products that are outputs from a process or product system. For example, in a refinery, gasoline, diesel, and jet fuel are all co-products. There are three approaches to handling co-products in LCAs: All co-products can be included within the LCA boundary (system expansion). It may be possible to split or separate a process into two or more sub-processes that describe an individual product. When the goal of a study is to evaluate a specific co-product (e.g., gasoline) and it is not possible to expand or split the system, a portion of GHG emissions must be allocated to each product, and only consider the GHG emissions associated with making and consuming the co-product of interest. ISO standards suggest avoiding allocations when possible via system expansion and process division. When it is not possible, ISO recommends allocating according to the underlying physical relationships between products.

In Section 3, the results of the analysis in Sections 2.1 – 2.4 will be compared with the key design elements identified by ICF to determine the rigour of the JEC analysis.

2.1 Conventional Crude Oil Production

The data sources and methodology used to determine the emissions from the crude oil production stage should take into account the following key design factors:

- Data for crude oil production should be determined via first principles engineering estimates or third party verified data.
- The data should be disaggregated to the maximum extent feasible and represent specific reservoirs or crude oils.

- If the intent of the FQD directive is for average crude oil consumed in the EU, than the data should represent the average crude oil extracted and delivered to EU refineries from reservoirs or fields, rather than the marginal unit of crude oil delivered to the EU.

GHG emissions from crude oil production can be estimated in two primary ways:

- **First Principles Engineering Estimates**. The methodology uses a bottom-up reservoir-specific calculation, focusing on energy consumption for various processes. For each process, an emissions factor is assumed. The key variables include the type of crude oil recovery (primary, secondary, or tertiary), water-oil-ratio (WOR), gas-oil-ratio (GOR), the reservoir depth, and the API of the crude.
- **Third Party Verified Data**. Using verified emissions or energy consumption data from crude oil producers, one can estimate the GHG emissions attributable to crude oil production. The reliability of this methodology is a function of factors such as data coverage and data quality. Given the number of fields and crude streams, the availability of reliable data for most lifecycle analyses is limited.

The boundary conditions of crude oil production can be complicated because the crudes that are marketed and sold to refiners are often blends of petroleum oils from one field or multiple fields. This means that determining energy and emissions for singular crude could require performing an analysis over multiple fields and regions. Conversely, multiple crude oils could be produced from a single field. In the case of the GHG intensity of crude oils, the contributions (intensity and volume) from each field into the production of a marketed major crude oil should be quantified in order to weight the relative contributions from each field. [5]

Given that the FQD is focused on average crude oil feedstocks supplied in the EU and reducing the GHG emissions intensity of transportation fuels, the GHG emissions intensity of the crude oil production should represent the emissions attributable to a representative crude supply – rather than the marginal unit of crude – delivered to EU refineries.

2.1.1 Main Data Sources

The primary JEC data sources for emissions from crude oil production are reports published by the International Association of Oil and Gas Producers (OGP). Table 5 summarizes the assessment against the four critical elements in Table 3.

The JECv4 report also references the BP Statistical Review and data from the International Energy Agency (IEA) with regard to statistics on energy production, energy consumption, and the crude sources to the EU. The IEA works with Eurostat to collect energy data from EU countries, as legislation requires each EU Member country to submit these data.[6] ICF did not perform a critical review of the data from

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[5] Appendix D includes an illustrative discussion and table to demonstrate the potential pitfalls of conflating or confusing GHG emissions intensity from MCONs, companies, and fields.

[6] Regulation No 1099/2008 of the European Parliament on energy statistics was promulgated in October 2008. For oil and petroleum products, data collection requirements include: energy products (such as crude oil, natural gas liquids—22 total listed), aggregated energy products (such as liquids produced from coal), and imports/exports.

the BP Statistical Review and the IEA in the same level of detail because these data are used throughout industry as the most accurate publicly available information. The data are used to determine the crude slate of imports to EU refineries; they are much easier to come by than energy consumption and emissions data associated with crude oil production because in many crude production countries, that information is privately held and not disclosed by producers.

Table 5. Analysis of Crude Oil Production Data Sources

Critical Element	OGP 2005	OGP 2011	ICF Analysis
Reliability	• Voluntarily submitted, resulting in low data coverage and potential selection bias (e.g. the best producers submitting data, skewing results). • OGP data are a combination of crude production and natural gas production. • Values based on OGP Members' company-specific quantification and reporting. • OGP provides Member companies access to similar guidelines to report GHG emissions but does not impose set standards.		• It is impossible to verify if OGP's stated data coverage is accurate for just crude oil production because the OGP data are a combination of crude production and natural gas production. OGP's stated percentages may be skewed to gas production in one region and crude oil production in another. • Voluntary reporting requirements and potential for multiple, competing methodologies may limit the reliability of the data.
Accuracy	• Data aggregated by industry (i.e., average emission per unit of combined total oil and gas production). • Data aggregated by regions (i.e., Europe, Africa, Asia, Middle East, North America, South America, and Former Soviet Union). • Uneven coverage/representation of oil and gas production regions. • Uneven coverage/representation of emission sources (flaring, venting and production). • A limited number of OGP Member companies reporting possibly resulting in selection bias, the distribution on their owner assets, and differences in methodologies (as opposed to industry environmental performance).		• Difficult to discern the accuracy and reliability of the OGP data because the documentation of the data are aggregated in OGP reports. • Combining two distinct industries of crude oil production and natural gas production introduces uncertainty. • Limitations in data accuracy from uneven coverage by region and emissions sources; increases in data do not necessarily mean more accurate results due to aggregation; could potentially skew the results to less representative values.

A complete list of energy statistics required are available online, Section L 304/33–Section L 304/41: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:304:0001:0001:EN:PDF.

Critical Element	OGP 2005	OGP 2011	ICF Analysis
Vintage	2005 data used for 2011 JEC v3 report.	2011 data used for 2013 JECv4 report.	JEC 2013 uses more up-to-date data but still has very limited coverage.
Quality	OGP Data do not represent the GHG intensity of all conventional crude oil production of fuels supplied to Europe.	Minor improvement in coverage (3% increase) for crude delivered to the EU compared to OGP 2005 data for all regions.	Lack of data coverage is a significant source of uncertainty in the JEC analysis of crude oil production.

ICF has identified the data coverage for OGP reported data as a significant source of uncertainty in the JEC analysis of crude oil production. The *OGP Environmental performance indicators—2011 data* report states:

> This report only reflects the performance of the OGP member companies that have provided data. However, where the degree of coverage is highest—for example in Europe where a high percentage of hydrocarbon production is represented—the information can be taken to approximate "industry" performance. In Africa, Asia/Australasia and South America, the data give a broad indication of industry performance. For the Middle East and North America, the regional coverage is less comprehensive, giving a weaker indication of industry performance. For the Former Soviet Union (FSU), data reported by participating companies represent just 9% of the total sales production for that region. Data for this region are therefore only representative of the performance of those companies reporting and not of the industry as a whole.

Despite this warning, the JEC report scales the GHG intensity for FSU crude oil production—representing less than 10% of production for the entire region—to a proportion consistent with crude oil shipped to EU refineries.

As noted in Table 5 above, there is modest improvement in the data coverage between the 2005 and 2011 data sets—a 3% increase in production data for crudes delivered to the EU, as shown in Table 6 below—with the improvement largely attributable to the Former Soviet Union and the Middle East region.

Table 6. OGP Data Coverage

Region	Global Data Coverage		EU Crude Sources	Weighted EU Coverage	
	OGP, 2005	OGP, 2011	2010 estimates (OGP, 2011)	OGP, 2005	OGP, 2011
Africa	66%	64%	17%	11%	11%
Asia	46%	43%	0%	0%	0%
Europe	98%	111%*	26%	25%	26%
FSU	4%	9%	37%	1%	3%
Middle East	16%	23%	18%	3%	4%
North America	29%	20%	1%	0%	0%
South America	53%	37%	2%	1%	1%
Total				**42%**	**45%**

Note: OGP production figures include oil and gas volumes consumed in operations and thus may exceed sales volumes reported in the BP Statistical Review

* This value was capped at 100% to calculate the weighted average in the last two columns of the table.

Apart from data coverage, it was challenging to discern the accuracy and reliability of the OGP data because the documentation is aggregated in OGP reports. The most critical issues that ICF identified include:

- **Estimation methodologies**. The OGP data are reported on a voluntary basis. This may introduce a selection bias into the results reported for the GHG emissions intensity of crude oil production. More specifically, the OGP data may introduce error or uncertainty due to sampling bias (a subset of selection bias) because the member companies voluntarily reporting data are not randomly selected and may not represent the entire industry. The reports have valuable statistics regarding number of companies reporting and regional coverage. However, the reports do not indicate the methodologies that were used to estimate emissions. The OGP provides guidance to reporting companies using a tiered approach (OGP 1994). When submitting data, the OGP forms ask the reporting entity to identify the estimation methodology based on either a) OGP Tiers 1-5 (see Table 7 below), b) API methodology, or c) some other methodology.

Table 7. OGP Tiered Data Sources

OGP Tier	Brief Description
Tier 1	Gas and oil production data factorised on a regional basis to give a preliminary estimate of emissions
Tier 2	Factorised fuel consumption and quantity of gas vented and flared
Tier 3	Application of emission factors to generic pieces of equipment (e.g., gas turbines)
Tier 4	Application of equipment specific emission factors and operation data such as load variations
Tier 5	Emission data derived from direct measurement.

To assess the robustness of the data, it is necessary to have a breakdown regarding the estimation methodologies employed by reporting companies; however, this information is not disclosed. Ideally, additional detail would be provided, including the (updated) emissions factors used for Tier 3 and Tier 4 estimation methodologies (assuming that the values provided in the OGP report from 1994 have since been updated).

- **Data for hydrocarbons includes crude oil and natural gas.** The OGP data are based on total hydrocarbon production in regions. Companies that report to OGP are requested to distinguish between liquid (e.g., crude) and natural gas production in the OGP reporting form (see Appendix A). However, for reasons unexplained, the OGP reports combined crude oil and natural gas production data. Thus, emissions are reported per-unit of hydrocarbon production. This does not enable the calculation of GHG intensity for only crude oil. Generally, natural gas production is less GHG intensive than crude oil production, as it rarely requires equipment like gavel pumps or secondary and tertiary extraction techniques. By combining natural gas and oil production, the resulting data used likely underestimated GHG intensities of crudes referenced under the OPG data set.

2.1.2 Methodology

Table 8 below identifies the details of the JEC methodology for determining the GHG intensity from oil production.

Table 8. Analysis of Crude Oil Production Methodology

LCA Methodological Aspect	Description	ICF Analysis
LCA Boundaries	• Regional oil and gas production industry for EU crude oil import slate.	• Boundary conditions should be limited to crude oil and associated gas production and exclude non-oil related natural gas production. • Does not include crude oil for US refineries to produce diesel for export to the EU, which could have significant effect on GHG intensity depending on the crude oil feedstocks.

LCA Methodological Aspect	Description	ICF Analysis
Inputs and Modeling Assumptions	• Implicitly assumed that there are no differences in GHG intensity among oil and gas recovery practices (primary, secondary, water flood, onshore, offshore) due to reservoir's characteristics and lifetime production as well as crude oil quality (light, medium, and heavy crudes). • Implicitly assumed that there are no differences in oil production from adoption of GHG mitigation measures such as cogeneration and/or flaring. • Uncertainty in oil production GHG intensity is associated only to flaring emission sources. • EU crude oil supply GHG intensity is assumed to be represented by a country prorated GHG intensity based on regional contribution of oil supplies as opposed to average GHG intensity for all countries within the region. • The report does not present energy density values used to convert OGP data.	• Implicit assumptions in the current methodology do not allow for calculation of emissions from crude oil recovery alone, leading to a potential underestimate of the GHG intensity from crude oil production. • Specific crude oil recovery practices for each reservoir and marketable crude oil name (MCON) should be analysed and taken into account and not averaged over all of oil and gas production by region.
Data Quality and Transparency	• The data source reports regional Oil and Gas Industry GHG intensities based only on OGP Member companies submitted data. • OGP data are representative of approximately 45% of EU crude oil supply, mostly due to coverage in European and African Regions. The FSU is a major supplier (37% of EU crude); however, OGP data coverage of the FSU is only 9%. • Data does not apply specifically to crude oil quality or refinery feedstock type.	• Because the OGP data are a combination of crude oil production and natural gas production it is impossible to verify if OGP's stated data coverage is accurate for just crude oil production. • Robustness of data are not validated to address technical and temporal data issues and potential implications. • Using limited data submitted from OGP member companies introduces the risk of selection bias (i.e., skewed data).
Allocation, Co-Products, and Offsets	• It does not appear that the allocation of emissions from hydrocarbon production, which includes both liquids and gases, was performed.	• Potential significant uncertainty with using aggregated data for hydrocarbons production (e.g., potential under- or over-estimates of regional GHG intensity).

ICF found it difficult to assess the transparency of the values/data that were used to arrive at the GHG intensity of crude oil production, as shown in Table 8. For instance, the JEC must have made assumptions regarding the energy content of the hydrocarbons produced in order to convert the data provided by the OGP reports—reported in energy consumption per tonne of hydrocarbon production (e.g., in Table 3.1.1-1 in JEC v4). However, it is unclear what energy density values (e.g., MJ/t or MJ/kg) the JEC used. These values must also reflect some assumptions regarding the split between liquid and gas hydrocarbons in the production values. The JEC report does not indicate how these conversions or allocations were made. Assuming that the data sources were entirely robust and accurate, it remains difficult to determine how the global crude oil production estimate (3.79 gCO2e/MJ in the JEC v3c report and 3.69 gCO2e/MJ in the JEC v4 report) and the GHG emission intensities for crudes used in the EU (3.9 gCO2e/MJ in the JEC v3c report and 2.89 gCO2e/MJ in the JEC v4 report) were calculated.

ICF found that the JEC v3c report understates the uncertainty associated with the methodology employed; the report states that they are "obliged by the absence of alternative global data sources" to adopt the GHG emission intensity value for crude oil production. Ultimately, the JECv4 report includes a GHG emission intensity value of 1.5 gCO2e/MJ for crude oil production, which is calculated based on the assumption that 51 percent of the 2.89 gCO2e/MJ from crudes is attributed to energy use. The other 49 percent is attributed to flaring (35 percent) and venting/fugitive losses (14 percent). The JECv4 report indicates that through analysis of other data sources, the estimate for the GHG emission intensity attributable to flaring is increased from 1.0 gCO2e/MJ (using OGP data) to 2.4 gCO2e/MJ. The fact that there is a 140 percent difference between the GHG emission intensity values estimated for flaring using OGP data and other data sources is not discussed in the context of crude oil production or venting/fugitive losses at all.

2.1.3 Summary

The JEC Reports (v3c and v4) relied completely on OGP data (OGP 2005 and 2011) for the crude oil production stage of the LCA. This stage adopts an average approach, which is appropriate given the FQD's objective of representing the average EU crude supply; however, methodology does not represent the average of all crudes consumed. This is because **the data used are limited for the purposes of an LCA due to the lack of coverage, aggregation by region and combining of crude oil and natural gas production**. A bottom-up engineering analysis of crude oil production for each major country and MCON would provide more extensive crude oil production coverage.

2.2 Venting, Flaring and Fugitives

The data sources and methodology used to determine the emissions from the crude oil venting, flaring and fugitives production stage must take into account the following design factors:

- Reservoir-specific associated gas production, venting, flaring and fugitive emissions
- In the absence of the above, the use of the most up-to-date US National Oceanic and Atmospheric Administration (NOAA) data for flaring. NOAA data has been referenced in a variety of studies including Jacobs (Jacobs 2012), California's OPGEE model (OPGEE v1.0), KPMG (KPMG 2011) and CanmetENERGY (CanmetENERGY 2012)

- Allocation of all flaring emissions to oil production since gas-only production is optimized to maximize gas recovery and minimize natural gas loss and flaring. This is a widely accepted practice in industry studies; Jacobs (Jacobs 2012), KPMG (KPMG 2011), and CanmetENERGY (CanmetENERGY 2012) all specify flared gas as associated gas in oil production
- A bottom-up calculation of fugitive emissions associated with crude oil recovery based on unit processes, gas-to-oil (GOR), and energy consumption during oil recovery; both Jacobs and the OPGEE model use a bottom-up engineering approach to estimate fugitive emissions
- Field-specific data for the ratio of vented-to-flared associated gas

2.2.1 Data Sources

Table 9 summarizes the analysis of the JEC data sources for venting, flaring and fugitives[7] according to the critical elements identified in Table 3.

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[7] Venting, flaring, and fugitives all refer to natural gas disposed along the gas supply chain for various reasons, intended or unintended. Flaring refers to the gas combusted at production sites, refineries or gas processing plants. Most flaring happens at oil production sites where insufficient gas pipeline capacity is available. Venting and fugitives, as opposed to flaring, are non-combusted emissions. Venting estimates include uncombusted flare gas in addition to purposeful releases from the use of gas dehydrators, AGR (acid gas removal) units, compressors, gathering pipelines, and overall well workovers and cleanups. Fugitive emissions are unintended releases based on factors for leakage rates of oil and gas production equipment.

Table 9. Analysis of Venting, Flaring, and Fugitive Data Sources

Critical Element	NOAA 2011	OGP 2005 and 2011	ICF Analysis
Reliability	• NOAA gas flaring volumes are estimated using satellite nighttime light data captured in the Defense Meteorological Satellite Program of the U.S. Department of Defense. • NOAA flaring data are widely used by the World Bank's Global Gas Flaring Reduction (GGFR) partnership, which includes numerous countries, companies, and multilateral organizations. • NOAA data are aggregated by country.	• Venting, flaring and fugitive loss data voluntarily submitted annually by 28 OGP member companies operating in 55 countries to provide "representative environmental performance of the upstream oil and gas industry" (OGP 2005). The data coverage is very low. Although the 2011 data expands coverage to 75 countries, the percentage of global oil and gas production covered in the report decreases from 34% to 32%, and about 45% of oil consumed in the EU. • Participating companies must provide information on their quality assurance systems.	• NOAA flaring data are considered the most complete and accurate data source on global flaring available; it is the best publicly available data for flaring worldwide. Many countries in the world do not report third-party audited flaring data. • OGP Data are less reliable and comprehensive with limited coverage and uncertainty from voluntary reporting requirements.

Critical Element	NOAA 2011	OGP 2005 and 2011	ICF Analysis
Accuracy	• Data are produced from the Defense Meteorological Satellite Program. • There are three important factors that define the limits of current flaring volume estimates: 1) The capability to identify flares from lights during nighttime imaging—limited by assumptions on flare brightness, duration, and location. 2) The extent that light brightness reflects flaring volumes—affected by surface reflectance, humidity, solar glare, artificial lighting, black carbon, and smoke. 3) The uniformity of conditions across various regions.	• Data summarized by seven regions: Africa, Asia/Australasia, Europe, FSU, Middle East, North America, South America. • Uneven data coverage means some regions, particularly Europe (98% coverage), have significantly better accuracy than others, such as FSU with only 4% coverage.	• NOAA has generally reliable data for flaring with global coverage but limited to only nighttime data. • There are limitations in OGP data accuracy due to uneven coverage by region and emissions sources.
Vintage	• 2008 Data (JEC v3c) • 2010 Data (JEC v4)	• 2005 data (JEC v3c) • 2011 data (JEC v4)	• JEC v4 uses the most recent data and more similar years of combined data.

Critical Element	NOAA 2011	OGP 2005 and 2011	ICF Analysis
Quality	• Data give an aggregate volume of gas flaring. • Data are for flaring only and are aggregated by country. NOAA also provides shape files that provide location but not magnitude of individual gas flares. • NOAA estimates are based on remote sensing data and have some limitations including no representation of daytime and offshore data, and difficulty with distinguishing gas flares from other light sources, among others.	• Venting and fugitive losses data represent performance of member companies only, which are dominated by international oil companies (IOCs). • Venting and fugitives emission data are expressed as tons of GHG (such as CO2, CH4, etc.) per tons of hydrocarbon production (which includes oil, condensate and gas). • Data are aggregated by different stages of production (drilling, process& treatment, flared, vented, etc.) or regional basis.	• International oil companies may have somewhat better performance in emission reduction than small companies, as JEC notes in v3 report. • Since NOAA data are an aggregate volume of gas flaring, there is no indication of the composition of the flare gas[8] or variations in flare efficiency by country or region. • NOAA remote sensing data has some limitations including no representation of daytime and offshore data and difficulty with distinguishing gas flares from other light sources. • OGP does not separate data between oil and gas production venting and fugitive losses. The data does not show differences in emission due to field characteristics.

The JEC reports used NOAA flaring data estimated from satellite images in 2008 and 2010. NOAA is considered the best publicly available data source on global flaring, as it uses independent estimation rather than relying solely on self-reported flaring. However, the JEC reports do not conduct an uncertainty analysis of the NOAA flaring data. Both versions of the JEC report consult the venting and fugitive losses data from the OGP. The third version of the JEC report uses the OGP data from 2005 and the fourth uses the 2011 data. In version v3c of the JEC report, NOAA's 2008 flaring data are combined with 2005 oil and gas production data from BP and crude oil consumption from 2008 to estimate a flaring emission estimate for the average crude imported into Europe. There might be regional and country level changes in patterns of production and flaring technologies from 2005 to 2008, making this

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[8] Different flared gas compositions may produce different impacts measured in CO2 equivalent. This is because each component in the flared gas which could include light hydrocarbons (C1-C4), nitrogen and CO2 has unique potential to retain heat in the atmosphere relative to CO2. It is not uncommon to see different flare gas compositions for different oil fields, due to particular field characteristics and gas pipeline capacity available.

combination less desirable. Version 4 of the JEC report better addresses the data vintage issue by combining NOAA's 2010 flaring data, 2010 data from BP and IEA, and 2011 data from OGP.

While the JEC version 4 report made use of the latest OGP report, the quality of OGP venting and fugitive losses data and the extent the data can be applied to the European crude slate is unclear. As mentioned in section 2.1.1, OGP obtains data voluntarily submitted by its members and the data are far from representative of the actual crude feedstock consumed in European refineries. OGP has very poor coverage of FSU and Africa, both of which are major suppliers of crude oil into Europe. Another weakness of OGP data is the lack of granularity. The report aggregates emissions in tons of GHG per ton of hydrocarbon production (i.e., combining oil and gas production), whereas the focus of the JEC report is on crude oil. Ideally, there should be a clear breakdown between oil and gas production and a clear representation of the impacts of field-specific characteristics. The differences in emissions, as well as the ratio of flared versus vented gas due to field-specific characteristics, are not accounted for. ICF thus believes that the use of OGP data to estimate venting and fugitive emissions for crude oil into Europe does not meet the necessary rigour.

2.2.2 Methodology

Table 10 below identifies the details for the JEC methodology for determining the GHG intensity from oil venting, flaring, and fugitives.

Table 10. Analysis of Venting, Flaring, and Fugitive Emissions Methodology

LCA Methodological Aspect	Description	ICF Analysis
LCA Boundaries	• Flaring and venting associated with crude oil production only, which does not include crude oil transportation to markets or processing/refining.	• The LCA boundaries should include VFF from all aspects of operations and include bottom-up estimate of fugitive emissions.
Inputs and Modeling Assumptions	• To obtain an estimate for production, flaring, venting and fugitive emissions, the JEC report constructs a European crude slate from OGP data by re-weighting regional emission figures in OGP by actual origins of crude oils consumed in Europe. The resulting venting and fugitives percentage estimate is used in the final figure in the JEC report. • The JEC report uses country estimates of flaring from NOAA. The flaring volumes are converted into tons of CO2e. This is then divided by total oil and gas production and total oil production (BP Statistical Review data) to establish lower and upper bounds of emission per country, respectively. Next, a weighted average of EU crude oil consumption from each country is estimated based on actual EU consumption (IEA 2012) and used to establish an average crude emission range (JEC v4). • To convert the volume of flare gas in bcm into tons of CO2e, the JEC report assumes a flare gas composition of 50% methane (CH4) and 50% ethane (C2H6) by mass or about 65% methane and 35% ethane by volume; 11% of the CO_2 conversion factor is contributed by unburned methane and ethane (JEC v4). • The JEC report uses a global warming potential (GWP) of 25 for CH_4 and a 98% flare combustion efficiency.	• The underlying assumption that the percentage of emissions allocated to production, flaring, and venting is equal between regions is not accurate. • The methane/ethane ratio does not match typical US flare gas composition of 78.8% methane and other gases by volume. • ICF considers the GWP of 25 as GHG coefficient for CH_4 and 98% flare combustion efficiency conservative assumptions appropriate for this study since factors are standards used in the industry. A sensitivity of 90-98% should also be considered since many countries many not use the industry standards for flaring and flaring efficiency data are not widely available worldwide.

LCA Methodological Aspect	Description	ICF Analysis
Data Quality and Transparency	• Flaring was divided by total oil and gas production. • An unreferenced flared gas composition was assumed. • JEC chose the midpoint of the range for the report as the final value. • Flaring was estimated from NOAA data. • Production, venting, and fugitives from OGP data were based on the following percentages: 51% production energy use, 35% flaring, 14% venting and fugitive losses (JECv4). • JEC v4: Flaring and venting total was 2.8 gCO2e/MJ; 2.4gCO2e/MJ for flaring (NOAA) and 0.4gCO2e/MJ for venting and fugitive emissions (OGP). • JEC v3c: 2.5gCO2e/MJ for flaring; unclear flaring to venting ratio.	• The venting and fugitives estimate may be inaccurate given the limited coverage of OGP data. • The use of total oil and gas production as the denominator for lower bound estimate maybe in accurate as most flaring happens in oil production. • The rationale for the flared gas composition assumption is not fully explained. • Unclear rationale for choosing the midpoint of the range for the report as the final value.
Allocation, Co-Products, and Offsets	• None	• All flaring should be allocated to oil production; venting and fugitives should be calculated from oil production processes and operations.

The JEC report flaring estimate is derived using NOAA data. A standard practice is to convert the provided volumetric data into tons of CO_2 equivalent using a set of benchmark assumptions on flare combustion efficiency, flare gas composition, and global warming potential values. Flare combustion efficiency and flare gas composition data are not widely available internationally on a field-by-field basis, so certain assumptions have to be made. JEC v3c does not state what assumptions the authors use regarding flare efficiency and flare gas composition. The v4 report assumes a flare gas composed of 50% methane and 50% ethane by mass for all crude suppliers into Europe. **The rationale for this assumption is not stated in the JEC v4; it has very high uncertainty associated with it and will have a material impact on the final flaring estimate.**

It is important to note that NOAA data do not explicitly allocate emissions to oil or gas production. However, most, if not all, flaring happens in oil production because gas producers are likely to have sufficient pipeline capacity to capture and bring the gas to markets. In both JEC reports, the authors establish a lower and upper bound of emissions by dividing the flaring volumes in tons of CO_2e by total oil and gas production and total oil production, respectively. The final value is the midpoint of the bounds. **This methodology is inaccurate and likely to underestimate the actual flaring volumes from oil production.**

In the JEC v4 report, JEC uses 0.4gCO2e/MJ as the final value for venting and fugitive losses based on calculations with data from OGP. This is within the range of venting emissions in the Jacobs report (0.047–0.564 gCO_2e/MJ). Note, however, that the Jacobs study covers specific crudes rather than the average crude slate into Europe. High imports of high venting emission crude such as certain crude streams from Brazil (venting emissions of 0.564 gCO_2e/MJ for Tupi crude in Jacobs) in any given year can easily increase the emission of the average crude into Europe. Ideally, venting and fugitive emissions are estimated from field-specific data. As shown in section 2.2.1, country averages are not provided in either the 2005 or 2011 edition of the OGP report. **Using broad regional averages as the basis for calculation significantly lessens the accuracy of the estimates.** Production technologies and reservoir conditions vary from field to field and between producers in the same region, resulting in different emission profiles. However, this is not reflected in OGP data.

2.2.3 Summary

NOAA (NOAA 2011) is the source for the most accurate, publicly available flaring estimates. All flaring should be assigned to crude oil product instead of the JEC assumption of taking the midpoint between allocating flaring to only crude oil production and to crude oil and natural gas. The OGP data (OGP 2005 and 2011) for venting and fugitives is based upon voluntary surveys of emissions and high level allocations to venting and fugitives and is not based on venting and fugitive factors for actual crude oil production operations and equipment. Since it is not based on these results, the OGP data underestimates the emissions from venting and fugitives and is insufficient for LCA use.

Data are not available for the efficiency of flares in producing fields across the world, including top flaring countries such as Russia, Nigeria, Iran, Iraq, etc. Therefore, LCA studies need to make assumptions of these flare efficiencies. Because natural gas is converted to CO2 through combustion in a flare and methane has a GWP of 25 (versus a GWP of 1 for CO2), a drop in flare efficiency of 8%, can raise the GHG emissions by 230%[9]. Based on research of observed flaring efficiencies by the University of Texas (Allen 2011), flaring efficiencies of 90%, 95% and 98% were used in Section 5 to perform a sensitivity analysis for determining an estimated most likely range of GHG intensity for conventional crude oil.

2.3 Crude Oil Transport

The data sources and methodology used to determine the emissions from the crude oil transport stage must take into account the following design factors:

- Accurate inputs for emissions per mile from tankers and pipelines for each specific country and destination. Pipeline compression uses different fuels and efficiencies in each region
- Determining the transport on a reservoir-specific basis creating a total pre-refinery value for each crude/reservoir

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[9] See Appendix D for an example.

2.3.1 Data Sources

Various sources were used to determine the factors and emissions for crude oil transport. For this portion of the analysis, the focus was on crude oil transport, as all finished products, irrespective of the feedstock, are transported in the same manner. Table 11 below summarizes the review of the JEC data sources by the critical elements identified in Table 3.

Table 11. Analysis of Crude Oil Transport Data Sources

Critical Element	TotalFinaElf, Shell	GM 2002	GEMIS	SPDC, 2000	ICF Analysis
Reliability	• Voluntary data submission by the energy company or individual for the purpose of the JEC study. The reliability of the data are unknown.	• The relevant data was mainly from energy companies who worked with LBST[10] as active participants, the reliability of this data are unknown; the only relevant data appears to come from literature rather than directly from energy companies; this data are regional in nature.	• The GEMIS database is regional in nature, covering all EU-27 countries for energy. Transport processes are based on EU and US data; the original data sources include academic research and other LCA databases.	• The data was verified by a third party, KPMG. However, the referenced data (HFO 0.0101 MJ/MJ crude) does not appear in the highlights report.	• Most data was not accessible, and therefore the overall reliability is low or unknown.
Accuracy	• No comment on accuracy can be made.	• No comment on accuracy can be made for the data sourced directly from energy companies; use of the Euro IV standard truck would be representative of the region.	• Older versions of GEMIS were used in this study and are no longer available for download. It is therefore unknown whether the original data sources can be considered accurate.	• The third party verifier, KPMG, found weaknesses in the accuracy and completeness of the data and/or in the control environment; however, it is unknown if this finding is directly related to the referenced data, which was not found in the source.	• For known data, ICF agrees with KPMG who found weaknesses in accuracy and completeness.
Vintage	• No comment on vintage can be made.	• No comment on vintage can be made for the data sourced directly from energy companies; the use of the Euro IV standard truck for the period of study (2010-2020) may be outdated given that the Euro V standard went into effect in October 2008. However, this would depend on typical truck turn over in this industry.	• Given that older models of GEMIS cannot be downloaded, it is unknown if any significant changes related to this data would have taken place between 1999 and 2002.	• Data could not be found in the referenced source; therefore, no comment can be made on vintage.	• It was difficult to find the exact data use to verify the vintage, but most of sources are over 10 years old.
Quality	• Given that the data source is direct information from an energy company or individual, this data are not reproducible, nor is it known whether it is representative, peer reviewed, etc.	• The data sourced directly from energy companies is not reproducible, nor is it known whether it is representative, peer reviewed, etc.; the literature data (Euro IV standard) is widely accepted.	• According to a review performed by the GHG Protocol, explanation of the GEMIS modelling approach is absent; it is unknown if it is compliant with any LCA standards. The data in this report is not reproducible.	• The data was presumably peer reviewed (third party verified). However, it is not reproducible, nor is it known whether it is representative.	• With the data being difficult to find, it is not possible to comment on the quality.

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[10] LBST = Ludwig-Bölkow-Systemtechnik GmbH

Overall, no definitive comment can be made on the quality and therefore rigour of the data (reviewed to date). Much of the data was provided directly by energy companies, with input data and subsequent calculations not made available. As a result, **the overall transparency of the data is poor** and it is therefore difficult to comment on the LCA rigour. The data and resources used for crude transport create single factors for various methods of transport rather than factors specific to a crude oil producing region or reservoir. As discussed in more detail below, JEC only devised crude oil production transport factors for Middle Eastern crude shipped to Europe via the Cape of Good Hope.

2.3.2 Methodology

Table 12 below identifies the details for the JEC methodology for determining the GHG intensity from crude oil transport.

Table 12. Analysis of Crude Oil Transport Methodology

LCA Methodological Aspect	Description	ICF Analysis
LCA Boundaries	• Included in the transport boundary are HFO (heavy fuel oil) production, HFO combustion (e.g., for shipping crude oil), crude oil transportation (by ship with HFO).	• Analysis should also include crude oil transport by pipeline and transport in ships smaller than VLCCs.
Inputs and Modeling Assumptions	• Assumed that marginal crude available to Europe would originate from the Middle East, (corresponding to 0.8 g CO2eq/MJ) in large ships (VLCC or ULCC—Very/Ultra Large Crude Carrier), travelling via the Cape of Good Hope to destinations in Western Europe. Crude transported from other regions (an average by reservoir approach) are not considered in this marginal methodology. • Pipeline transport (between production sites and ports, production sites and refineries, and ports and inland refineries) was not taken into account. • Given that the share of HFO production energy is small in the total pathway and that evaluating the energy associated with HFO production is difficult, assumed/applied a single net energy consumption value (0.088 MJ/MJ, 6.65 g CO2/MJ) for HFO production. • For crude oil transport (via ship), assumed an empty return trip. • No losses (e.g., fugitive emissions) from storage and retail distribution taken into account within the transport stage.	• An average analysis of transport distances, energy and emissions should have been done since more Middle Eastern heavy crude was imported to the EU in 2010. • The analysis should have taken into account smaller ships in addition to ULCCs and VLCCs.

LCA Methodological Aspect	Description	ICF Analysis
Data Quality and Transparency	• Overall, no definitive comment can be made on the quality of the data (reviewed to date), as much of the data were provided directly by energy companies. In addition, the actual input data and subsequent calculations were generally not made available.	• The overall transparency of the data is poor.
Allocation, Co-Products, and Offsets	• There were no allocations, co-products or offsets in the transport stage.	• No allocations should have been used in the transport stage.

The JEC uses a marginal methodology in estimating emissions from crude oil transport. The JEC assumed that the marginal crude to supply Europe would originate from the Middle East, rather than considering an average approach, where multiple production sites/reservoirs are considered; it would be difficult to determine if Middle Eastern marginal crude oil would be the first to be displaced or reduced. It is difficult to determine a singular marginal crude for the EU since each refinery is different and as will be discussed in Section 2.4, a refinery's selection of crude oils will be made not only by changes in the product slate but also potential future changes to refinery configurations. **ICF determines that an average approach that considers separate emissions from crude oil transport for each producer/reservoir and to each destination would result in a more accurate LCA.** An "average" approach would consider different transport modes used for each production site and destination resulting in different transport related emissions for each crude oil stream.

For instance, crude oil from Saudi Arabia may be extracted at Al Ghawar and piped to Yanbu, where it is transferred to ship and shipped via the Suez Canal and Strait of Gibraltar to Le Havre, France. In this case, transport emissions from pipeline and shipping modes must be considered. However, Sirri Island crude from Iran is shipped directly to Le Havre France, via the Suez Canal and Strait of Gibraltar; only shipping emissions would need to be considered for transport of this crude oil stream. Crude transport GHG intensity can vary between 0.1 – 2.1 gCO2e/MJ. Given the potential variability for crude transport not only between modes (e.g., pipeline vs. ship), but also within modes (e.g., pipeline energy source, ship size) emissions need to be considered separately for each unique source/destination.

The JEC also only considers what they assume to be the transport mode for the "bulk of Arab Gulf crude": in Ultra Large Crude Carriers (ULCC) and Very Large Crude Carriers (VLCC), travelling via the Cape of Good Hope to Western Europe. However, there are other options for crude oil travelling from the Middle East to Europe including intermediate pipeline and smaller crude carriers (e.g., Suezmax).

The JEC study also does not take into account pipeline transport of crude oil between production sites and shipping terminals (e.g., Middle East to Mediterranean, Caspian basin to Black and Mediterranean seas, Russia to Black Sea), ports and inland refineries (e.g., Mediterranean to North Eastern France and Germany, Rotterdam to Germany), or production sites directly to refineries (e.g., Russia to eastern Europe).

Under an "average" approach, if other crude oil producers were considered, additional ship sizes would also need to be considered for crude oil transport. Although most crude oil is transported in large tankers, smaller ships (e.g., 100 kt) are used to carry crude over shorter distances, such as from the North Sea or Africa to Europe, both of which represent significant sources of crude oil into the EU.

2.3.3 Summary

ICF was unable to identify many of the actual pieces of data that were identified in the JEC report since they are over a decade old, making it impossible to determine the reliability, accuracy, and quality of the data. For this reason, the overall transparency of the data is considered poor. The marginal methodology of determining GHG intensity for Middle East heavy oil travelling by tanker via the Cape of Good Hope is inaccurate and insufficient for determining the average GHG intensity of gasoline and diesel. The transport emission for all crude oils imported to the EU in 2010 should be calculated and used within the analysis. An average approach that considers separate emissions from crude oil transport for each producer/reservoir and to each destination would result in a more accurate LCA.

2.4 Crude Oil Refining Stage

The data sources and methodology used to determine the emissions from the crude oil refining stage must take into account the following design factors:

- The model should be based on EU-specific refinery configurations to ensure the result is the EU average
- It should determine the average energy and emissions for gasoline and diesel production from refining, given that the FQD is looking to reduce the average GHG intensity of transportation fuels
- While either a substitution or allocation methodology of energy and emissions can be employed, the assumptions and calculations must be transparent[11]
- An average methodology should be employed, either by product or crude since the FQD is looking to use the result to represent the average GHG intensity for gasoline and diesel

An assessment of GHG intensity for crude oil refining involves an understanding of energy users and how different processing scenarios can affect energy consumption. The largest energy users in a crude oil refinery are typically the fluid catalytic cracker (FCC) and fired boilers, heaters and furnaces. The hydrogen plant can also release significant CO2 from steam reforming of natural gas. To predict performance of the FCC, a significant knowledge of conversion and heat recovery is required. Typically, higher conversion results in greater coke, and the combustion of coke to regenerate the catalyst is often the largest single

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[11] Allocation is the methodology of dividing (allocating) the energy and emissions of a process or stage between the multiple products produced. Substitution is the methodology of allocating all emissions to the main product(s) and crediting the energy and emissions that other co-products substitute or offset. For example, many biodiesel LCAs use substitution when crediting the biodiesel with offsetting petroleum based glycerin production with the glycerin produced during transesterification.

source of GHG emissions at a refinery. Similarly, knowledge of boiler, heater, and furnace efficiency targets (excess oxygen and flue gas temperatures) is required to establish target fuel use.

2.4.1 Data Sources

The main data source of the crude oil refining stage for the JEC reports is the 2007 CONCAWE report (CONCAWE 2007). Although details of the CONCAWE Refining Model are not provided, there are indications that it is based on sophisticated process-specific information. More detail would, however, allow an assessment of the individual process energy requirement assumptions, such as efficient energy requirements (furnace efficiency from excess oxygen and fuel gas temperature) and product stream heat recovery before utility cooling. Conclusions on the impact of throughput changes are based on a constrained system and do not appear to consider potential changes in equipment or operations that would likely be based on cost considerations. This has the potential to change the conclusions on the impacts of relative amounts of product production. Table 13 below summarizes the review of the JEC data sources by the critical elements identified in Table 3.

Table 13. Analysis of Crude Oil Refining Data Sources

Critical Element	CONCAWE 2007	ICF Analysis
Reliability	• Although Table 4 of the CONCAWE Report shows that a sophisticated process-by-process analysis was conducted, the report does not disclose the process operational details needed to assess the model.	• Lack of transparency in the modeling analysis makes it difficult to ascertain the reliability of the data.
Accuracy	• CONCAWE report considers the potential for refiners to adapt refinery configuration and operations to address the demand mix changes but then models marginal changes in gasoline and diesel with no operational changes. • The differential energy consumption and CO2 emissions were fully allocated to the change in diesel or gasoline fuel production.	• CONCAWE report appears to consider the likelihood that refiners will adapt refinery configuration and operations to address the changes in product demand. However, there is no discussion of the difficulty in making these modifications and their potential economic impact. • If there was a change in demand that would significantly alter the required diesel to gasoline ratio, the conclusions in the CONCAWE and JEC reports would not likely be applicable. • There are ways to adapt and mitigate the potential changes from the increase in the diesel/gasoline demand ratio. These options do not appear to have been fully analysed. • Allocating only to marginal gasoline and diesel assumes a constrained system and does not consider potential changes in equipment or operations that would be likely based on cost considerations for future operations.

Critical Element	CONCAWE 2007	ICF Analysis
Vintage	• The report is over 5 years old (from January 2007).	• The report is likely obsolete since it is over 5 years old (from January 2007) and there have been changes with product slate demand in EU ETS regulations, such as reductions in the amount of sulfur in fuels, and a series of refinery closures in the EU. • It appears that the EU will adapt to changing product requirements as it has in the past. This would be expected in an economically guided endeavor. While this conclusion guides the analysis of potential changes needed, it was not adopted in the later JEC analysis.
Quality	• The data produced in the CONCAWE report, without access to the model is not reproducible.	• The results are not reproducible since the model is not available. The results are not representative of changes in refinery configuration that would occur after an increase in the diesel to gasoline ratio, as is suggested in the report.

The studies reviewed did not provide sufficient detail on the processing units to determine if the energy efficient operations assumptions were reasonable. The details of how hydrogen plant CO2 emissions were considered were not provided in the studies reviewed.

Expected fuel use depends on crude feed quality and product mix. Heavier and poorer quality crude requires more energy to process. Higher quality products (lower sulfur and higher octane gasoline) require more energy to produce.

A second point is that both the JEC analysis and supporting CONCAWE reports discuss the current and increasing imbalance between specific motor fuel demand and supply. A need to increase the ratio of diesel to gasoline in Europe is predicted; how that is achieved will have significant impact on energy intensity in the refining sector. The CONCAWE report appears to be open to investment and operational change opportunities to address the imbalance.

However, the CONCAWE report is likely obsolete since it is over 5 years old and some of the assumed projections (e.g. fuel sulfur level; available crude oils) do not appear to be applicable in the current environment. Although it raises similar concerns about increasing diesel to gasoline requirements, it appears to be more flexible than the JEC report in considering the potential for mitigation. The report states that the "way refineries process crude oil must, however, be adapted in order to cope with changes in the product slate, particularly with regards to the relative demands for middle distillates and gasoline." However, these potential changes were not incorporated into the analysis. If the refineries must change, then the expected operating scenarios used in this analysis may not be representative of future operations.

2.4.2 Methodology

Table 14 below identifies the details for the JEC methodology for determining the GHG intensity from crude oil refining.

Table 14. Analysis of Crude Oil Refining Methodology

LCA Methodological Aspect	Description	ICF Analysis
LCA Boundaries	• EU crude oil refining; all energy and emissions consumed at a refinery including hydrogen.	• Does not include refining of crude oil in the US for imported diesel. All transportation fuels, even imported, fall under the FQD.
Inputs and Modeling Assumptions	• Assumes that crude oil based fuels are manufactured from crude oil in European refineries. • 2010 base case including "all foreseen fuel specifications including sulphur-free road fuels, but excluding any effects of biofuel blending". • Gasoline and diesel maximum sulphur content were assumed to be 10 ppm. Other fuel specifications were assumed to remain at the legislated levels (i.e., maximum 35%v/v aromatics in gasoline). • Forecasts marginal increases in gasoline and diesel with heavy Middle Eastern Crude as the available crude oil.	• This analysis should be based on averages, rather than marginal changes. It should take into account the full product slate, not just gasoline and diesel, and should consider the EU average crude oil feed.
Data Quality and Transparency	• The methodology for refining is not explicitly described in the CONCAWE report or the appendices. • No assumptions were documented in the CONCAWE report. • There are no descriptions of the calculations for the refinery energy use or emissions.	• It is not possible to assess the adequacy of the methodology for refining since it is not adequately described in the report or the appendices. • There is insufficient documentation contained in the report to determine what assumptions were made about the configuration and design of the model refinery.
Allocation, Co-Products, and Offsets	• By only increasing or decreasing gasoline and/or diesel consumption, JEC avoids allocating emissions.	• The methodology should look at the EU average mix of crude oil, consider all of the emissions from the refining section inclusive of all products, and perform a thorough allocation and/or substitution process.

The report lacks thorough documentation of the methodology used for assessment of energy use and emissions from refining. Although there are numerous statements as to the transparency, the report lacks even simplistic descriptions of the base refinery used in the analysis, processes used, assumptions on energy use distribution, energy integration, and other efficiencies.

In JEC v4, there do not appear to be any significant changes from JEC v3c that impact the refining process. However, there are several assumptions that are more clearly documented in this more recent version that raise questions about their applicability to the future EU refining sector. Specifically, it is not clear that the current imbalance between gasoline (currently produced in excess) and diesel (demand exceeds local supply) will continue. Given the time horizon, it might have been more appropriate to assume that this imbalance would have been addressed by alternative feedstock or refinery process modification. Therefore, the assumption on the relative energy intensity of gasoline versus diesel is potentially inaccurate.

The study indicates that some liquid fuels used in refinery furnaces, boilers, and heaters would be replaced by gas. Given the recent trend in mandated sulfur reduction, it should have assumed that expected sulfur regulations would require that all liquid fuels be replaced by gas fuels. It states that this change would not impact energy intensity figures. This may not be an appropriate conclusion for 2 reasons: 1) many refineries have access to NG and if they increase their use of NG, then GHGs would most likely decrease; 2) If a refinery cannot gain access to more NG, then burning refinery fuel gas is still less emission intensive than burning liquid fuels, and would still result in a decrease of GHGs.

JEC utilizes a marginal methodology for the refining emissions, looking at not only the marginal barrel of crude used in the refinery (heavy Middle Eastern) but also the marginal production of gasoline and diesel. Marginal analysis is not an appropriate methodology to determine the average GHG intensity of the crudes consumed in the EU (as discussed in Section 2.4.3), as it is difficult to predict the exact marginal crude oil that would be displaced first if there were reductions in gasoline and diesel consumption. This is due to a combination of factors including which refinery/region is experiencing this reduction (proximity to various crude production), long standing purchasing agreements between crude producers and refiners, the preference by refiners without agreements to use certain crude oils, and the fact that crude oil is purchased on the spot market, which means the marginal crude today might not be the marginal crude tomorrow or next year or 10 years from now.

2.4.3 Summary

The CONCAWE report (CONCAWE 2007) used to determine the GHG intensity for refining lacks transparency and the values that it determined are not reproducible. The report notes that operational and process refinery changes would result from changes in the gasoline to diesel ratio. However, the modeling by CONCAWE in the JEC report changes the gasoline-to-diesel ratio while apparently maintaining the original refinery process and operation configurations. While this approach might be satisfactory for small incremental changes in product mix, it would not be appropriate for larger changes where economic and operational considerations would likely result in configuration and operational modifications. In addition, CONCAWE performs a marginal analysis for the gasoline and diesel mix by increasing and decreasing only gasoline or diesel production and allowing only changes in heavy Middle East crude. **This marginal methodology is not appropriate for estimating average gasoline and diesel GHG intensities. It lacks consideration of other useful refinery products and it is difficult to accurately select only one marginal crude oil that would be appropriate for all of EU refining.**

3 LCA Rigour of the JEC Report

Section 2 detailed the data sources and methodology of the JEC reports and how they differed from the identified LCA key design elements. Table 15 below summarizes the discussion in Section 2 and assesses whether the LCA Rigour of the JEC Report is sufficient for use within the FQD.

Table 15. LCA Rigour of the JEC Report

LCA Stages	JEC Report
Crude Oil Production	The JEC report has several limitations regarding key design factors to determine the GHG intensity of crude oil production. More specifically, the following issues are identified: • Data Sources: – Data are reported voluntarily by the industry, likely introducing selection bias (more specifically, sampling bias). – Data are aggregated at a country and regional level. – Data are also aggregated as hydrocarbon production—which includes both liquids (e.g., crude oil) and gases. – Limitations on data coverage: Less than 50% of regions supplying crude to the EU report data. – Unclear what estimation methodologies were employed by Member Companies used to report data. Methodologies prorating the limited data coverage (by region) to the entire volume of crude supplied to the EU do not represent the differences between fields (e.g., recovery methods, mitigation measures, etc.) and is an inaccurate methodology.
Venting, Flaring and Fugitives	The JEC report has several limitations regarding key design factors for venting, flaring and fugitives. It uses the latest flaring estimates from NOAA, a satellite data source for flaring, but has no reservoir- or field-specific evidence to supplement its analysis. In addition, the JEC report does not conduct an uncertainty analysis of the NOAA flaring data. The JEC report uses the sum of oil and gas production as denominator for flaring estimates, but most if not all flaring in fact happens in oil fields where pipeline capacity is insufficient to transport the associated gas. The OGP data for venting and fugitives lacks the level of granularity necessary for the purpose of estimating the emissions level of the crude slate into Europe.
Crude Oil Transport	The JEC report has several limitations regarding key design factors with the use of a marginal analysis for crude oil transport by only taking into account the transport of a single type of crude oil. The FQD requires an average analysis for gasoline and should take into account the transport distances of all potential crude oils to the EU.
Crude Oil Refining	The JEC report has several limitations regarding key design factors for an LCA to determine the GHG intensity value for the FQD with respect to crude oil refining. The FQD requires an average analysis performed and the JEC produced marginal values for gasoline and diesel.

The data sources and methodologies used within the JEC report to determine the GHG intensities for gasoline and diesel have several limitations regarding key design factors for the most accurate LCA:

- The OGP data are limited for the purposes of an LCA due to the data’s lack of coverage, aggregation by region and combining of crude oil and natural gas production.
- The JEC report does not allocate all flaring emissions to crude oil production, which underestimates the GHG intensity and does not perform a bottom-up engineering analysis of venting and fugitive emissions.
- The refining and transport GHG intensities are determined using a marginal analysis, which does not produce the average GHG intensities required by the FQD directive.

4 Comparison of European Conventional Crude LCA Studies

The following table compares the JEC study with other studies that have performed LCAs for conventional crude oils in a European context or that are relevant for estimating the most likely range of values for GHG intensity in Section 5. The table compares important data sources and assumptions.

Table 16. Summary of Key Study Design Factors that Influence GHG Results

Estimated Relative WTW Impact		High	High	High	High	High	High	High	Medium	Medium	Medium	Medium	Medium	Medium	Medium
LCA Study/ Model	Data Reference Year	Was the Purpose of the Study to Determine a CI Value for Use in the FQD?	Is the Result of the Overall LCA to Be a Marginal, Average, or Crude-Specific?	Was the Resulting LCA Average, Marginal, or Crude-Specific?	Oil Production Based on First Principles Bottom-Up Calculations or Third Party Verified Data?	Oil Production Granularity: Reservoir, Country, Region	Bottom-Up Calculations of Fugitive Emissions	Are All VFF Emissions Allocated to Oil Production?	Reservoir-Specific Associated Gas Production and VFF Emission	World Bank/NOAA Data for Flaring and Vintage	Field/Reservoir-Specific Venting to Flaring Ratio	Country and Destination-Specific Transport Factors	Transport on a Reservoir-Specific Basis	Refinery Modeling Performed for EU Refinery-Specific Configurations	Substitution or Allocation Methodology and Transparency
JEC Study v3c	2005–2008	No	Marginal	Combined[1]	Third Party Data. Verification status unknown	Region	No	No. The lower bound of the range includes gas production	No	Yes. 2008 data.	No	No	No	Average EU refinery but marginal crude	Marginal increases/ decreases of diesel and gasoline.
JEC Study v4	2005–2011	No	Marginal	Combined[1]	Third Party Data. Verification status unknown	Region	No	Same as above.	No	Yes. 2010 data.	No	No	No	Average EU refinery but marginal crude	Marginal increases/ decreases of diesel and gasoline.
Brandt Study (NETL 2008)	2005	No	Average	Combined[1]	Regional aggregate -ed data	Region	No	Yes	No	Indirectly. Sources of Brandt study use NOAA.	No	No[2]	No	Uses JEC values	Uses JEC values

Estimated Relative WTW Impact		**High**	**High**	**High**	**High**	**High**	**High**	**High**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**	**Medium**
LCA Study/ Model	Data Reference Year	Was the Purpose of the Study to Determine a CI Value for Use in the FQD?	Is the Result of the Overall LCA to Be a Marginal, Average, or Crude-Specific?	Was the Resulting LCA Average, Marginal, or Crude-Specific?	Oil Production Based on First Principles Bottom-Up Calculations or Third Party Verified Data?	Oil Production Granularity: Reservoir, Country, Region	Bottom-Up Calculations of Fugitive Emissions	Are All VFF Emissions Allocated to Oil Production?	Reservoir-Specific Associated Gas Production and VFF Emission	World Bank/NOAA Data for Flaring and Vintage	Field/Reservoir-Specific Venting to Flaring Ratio	Country and Destination-Specific Transport Factors	Transport on a Reservoir-Specific Basis	Refinery Modeling Performed for EU Refinery-Specific Configurations	Substitution or Allocation Methodology and Transparency
Jacobs 2012	2000s	No	Crude Specific	Crude Specific	First Principles Bottom-Up Calculations	Reservoir (Research paper data),	Yes	Yes	Yes	Yes. 2007 data.	Yes	Yes[3]	Yes[4]	Uses individual crudes and individual refineries	Uses refinery yields based on individual crudes and individual refineries
ICCT 2010	2009	No	Crude Specific	Crude Specific	Meta-analysis	Reservoir	No	No. The lower bound of the range includes gas production	No	Yes. 2008 data.	No	Partial[5]	Partial[6]	Uses Jacobs' model	Uses Jacobs' model
OPGEE v1.0	2010	No	Crude Specific	Crude Specific	First Principles Bottom-Up Calculations	Reservoir/ Field	Yes	Yes	Yes	Yes[8]	Yes	Yes	Yes	NA[9]	NA[9]

Notes:

1. The LCA performs an average crude oil production and VFF analysis, and a marginal crude oil transport and refining analysis
2. The Brandt study refers to the JEC study for crude oil transport
3. The Jacobs report selected three European destinations for crude oil transport analysis—one refinery in each of Italy (inland), Germany (inland), and France (coast)
4. The Jacobs report selected a variety of reservoirs, specific to each destination, for crude oil transport analysis. They looked at 12 specific reservoirs for the refinery destination of France, 6 for Italy, and 7 for Germany.
5. The ICCT report considers only tanker transportation from the producer country terminal to a European refinery (refineries not specified).
6. The discussion in the ICCT report indicates that transport distances are determined on a reservoir basis. However, the ICCT report analysis only considers crude oil transport by tanker, and therefore only the distance from a gathering station (not a specific reservoir) to Europe.
7. The Brandt Study is based on the NETL 2008 for crude oil production and VFF and the JEC report for refining and transport. The Brandt study presents a range of upstream emissions for conventional crudes taken from the NETL 2008
8. Unless more accurate country, reservoir or field level data are available
9. OPGEE does not include refining emissions
10. NS—Not Stated

Table 17 shows the evaluation of the reports and models available to ICF to perform the analysis in Section 5; highlighted studies and models were selected for use in Section 5.

Table 17. LCA Study and Model Evaluation for Most Likely Range Analysis

LCA Study or Model	Crude Oil Production	Venting, Flaring, and Fugitives	Crude Oil Transport	Refining
Criteria	Bottom-Up Estimate for EU Crudes	1) Based on NOAA data and 2) allows for variation and flare efficiency	Results are on a Crude-Specific Basis	Includes total, not marginal, emissions from EU Refining
JEC Study v4	No	1) Yes , 2) No	No	No
Brandt Study (NETL 2008)	No	1) Yes , 2) No	No	No
Jacobs 2012	Yes	1) Yes , 2) No	Yes	No
ICCT 2010	Yes	1) Yes , 2) No	Yes	No
OPGEE v1.0	Yes	1) Yes , 2) Yes	Yes	NA
CONCAWE 2007	NA	NA	NA	Yes
🟨	LCA Studies and Models chosen for use in Section 5			

The JEC and Brandt studies were excluded from the analysis in Section 5 since they did not meet any of the necessary criteria. While the ICCT report did calculate a bottom-up estimate for various crude oils, the exact values calculated and methodologies used were not transparent; thus, ICCT report results were similarly not included in the Section 5 analysis. The Jacobs report does not easily allow for a variation in flare efficiency, but it does have significant coverage of EU crude-producing countries and transparent values for crude oil production, VFF, and crude oil transport. The OPGEE model was chosen as the main resource for the crude oil production, VFF, and crude oil transport. The data used for each MCON modeled are publicly available and transparent and all values calculated can be verified and reproduced. In addition, the model allows for variations in flare efficiency. Lastly, the CONCAWE 2007 report was used for the refining analysis. It contains actual data, as opposed to modeled, for EU refinery emissions that can be used to determine the GHG intensity from refining using allocation methodologies.

5 Estimated Most Likely Range of an FQD Default Value

ICF reviewed the referenced studies above and additional models and data sources to develop an estimated most likely range. Based upon the uncertainty of the available crude oil production and venting and flaring data, and the inability to gain access to propriety refining models, ICF chose to determine most likely ranges instead of most likely values for the GHG intensity of gasoline and diesel. The sources in Table 18 were reviewed to estimate this range.

Table 18. Data Sources for Estimating Most Likely Range

LCA Stage	Data Sources, Reports or Models
Crude Oil Production[12]	OPGEE, Jacobs
Venting, Flaring, and Fugitives	OPGEE, Jacobs
Crude Oil Transport	OPGEE, Jacobs
Crude Oil Refining	CONCAWE 2007
Finished Product Transport	JEC—to remain unchanged
TTW	JEC—to remain unchanged

The Oil Production Greenhouse Gas Emissions Estimator (OPGEE) Version 1.1 (OPGEE v1.0) model was developed for the California Air Resources Board (CARB) (OPGEE 2013_2). It is an engineering-based LCA tool for estimating GHG emissions from the production, processing, and transport of crude petroleum. The OPGEE model includes GHG emissions from initial exploration to delivery at the refinery and covers primary production/extraction, secondary production/extraction (e.g., water flooding), surface processing, major tertiary recovery technologies (e.g., enhanced oil recovery), maintenance operations, waste treatment and disposal, and bitumen mining and upgrading[13]. The model is developed based on what are referred to as MCONs: The input values for MCONs provide information for production methods, field properties, fluid properties, production and processing practices, land use impacts, and crude oil transport parameters for an uneven number of fields among different countries.

ICF used the EU crude slate listed in Table 3.1.1-3 of the JEC v3c report to develop the estimated most likely range. ICF only considered EU crude imports and refined products from EU refineries and did not calculate the GHG intensity of diesel imports from the United States. For this analysis, it was necessary for ICF to use immediately available data and results to determine an estimated most likely range. To estimate GHG emissions for crude oil production, ICF selected publicly available information (for transparency) and

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[12] ICF opted not to use other sources such as GHGenius and GREET because these LCA models include vastly different crude slates than the crude slate delivered to EU refineries. As a result, these tools suffer from some of the same limitations that have been identified for the JEC reporting. More specifically, the emissions from crude oil production are aggregated over regions (GHGenius) or an entire country (GREET). Furthermore, these models are based on refinery complexes in Canada and the United States, respectively, and lack utility in the context of this analysis.

[13] The OPGEE model uses a separate module based on GHGenius to assess bitumen pathways which includes inherent aggregation as described in the footnote above.

tools, including OPGEE and the 2012 Jacobs report, which allowed GHG estimates to be based on first principles bottom-up calculations. The ICCT and Brandt Reports do not have publicly available data and results derived from first principles bottom-up calculations.

ICF utilized a meta-analysis of existing models and studies in determining the LCA emissions for each of the stages, combining various studies that have different assumptions in modeling WTW GHG emissions. With additional time, ICF would have estimated the emissions using a singular model/methodology for all major crude oil MCONs and countries that are imported to the EU.

5.1 Crude Oil Production

5.1.1 Data and Methods

GHG emissions were calculated for those countries identified in the OECD EU 2010 oil consumption figures reported by the International Energy Agency Statistics and the BP Statistical Review in Table 3.1.1-3 of the JEC v3c report. Emissions estimates for each country were based on the OPGEE v1.0 model and associated input values for the various MCONs published by the California Air Resources Board (OPGEE 2013_2).

ICF chose to use an analysis based on MCONs and actual field data and use these as representative values over using data for an entire country or region. Using actual MCON and field data, while having limitations in coverage for a country, provides a better representation of energy and emissions associated with crude oil production.

GHG emissions estimates for crude oil production were developed using the following approach:

1. Estimate field GHG intensity
2. Estimate company GHG intensity
3. Estimate MCON GHG intensity
4. Calculate country GHG intensity
5. Calculate EU crude supply GHG intensity

Using the OPGEE model and MCON inputs, ICF was able to estimate the GHG emission intensities attributable to crude oil production for specific MCONs, and to determine country GHG emissions intensity based on the MCON origin and production volume. To determine MCONs, ICF followed the same method used by CARB. MCON GHG intensity estimates through OPGEE have been used to inform California's Low Carbon Fuel Standard (LCFS) (OPGEE 2013). Thus, in this study, the GHG emissions estimates at the production stage of the life cycle for each MCON are comparable with those considered in California's LCFS. The available data for MCONs allow crude oil production GHG intensity estimates for 13 out of the top 20 countries supplying crude to refineries in the EU. Of the 13 countries for which data are available, seven (7) of them were represented by more than one crude oil production field and/or MCON. The assumption was made to use the available MCON results as representative values for the countries where they are produced. This is one of the main limitations in the analysis since the MCONs evaluated do not cover the full production of each country and are not necessarily the same MCONs imported to the EU. [14] A more complete analysis would gather MCON-level data for EU crude oil imports and corresponding data for inputs into the OPGEE model for MCONs that are not currently covered. A weighted average of country GHG intensity was estimated based on MCON production volume, and a country GHG intensity range was defined as the minimum and maximum GHG intensity values for each MCON.

GHG intensities at the country level were used with IEA data to determine GHG intensity values for crude supplied to the EU in 2010. For those countries represented by only one MCON, the production GHG intensity value was adopted as the country average, maximum, and minimum values. GHG intensity values for major crude suppliers were calculated by weighting their contribution to the total crude oil delivery to the EU in 2010. The weighted minimum and maximum GHG intensity values represent the range in which the most likely value could vary based on changes in the MCON slate.

5.1.2 Results

Table 22 shows the GHG emissions intensity values for crude oil production excluding Venting, Fugitive, and Flaring emissions. Three sets of results are presented, as discussed in more detail below.

The first set of data, *OPGEE Only,* indicates the results when using the data and methods described above. As shown in the table, the MCON data and the OPGEE model enabled ICF to develop a GHG emission intensity estimate that represents about 59% of the countries that supply crude oil to the EU.

The second set of results, *Jacobs Only,* for crude oil production, venting, flaring, and fugitives, and transport were extracted only from the Jacobs report (Jacobs 2012). For countries with multiple crude oils analysed, these values were used to set minimum and maximum values. For countries with just one crude oil analysed, the assumption is made that this crude oil is representative of the country. As shown in Table 22, Jacobs data represent about 79% of the countries that supply crude oil to the EU.

The third set of results, *OPGEE + Jacobs*, includes values from OPGEE and values reported by Jacobs (Jacobs 2012). The objective of the Jacobs study was not to determine a FQD GHG intensity value and did not use the OPGEE model; therefore, results from the Jacobs report and the GHG emissions estimates for this study are not directly comparable. However, the Jacobs report reviewed the life cycle GHG emissions from major sources of crude consumed in Europe using first principles bottom-up calculations (similar to the OPGEE approach), and includes GHG emission estimates for crude oil production in countries such as Norway, UK, and Iran. These countries were significant sources of crude supplies to EU refineries in 2010 according to the IEA and combining OPGEE and Jacobs results increases the percent of crude supplied to the EU at a country level.

Table 22 shows that after including estimates from the Jacobs report with those obtained from the OPGEE model, the percent of countries that deliver to EU refineries in 2010 represented in our calculations (at the national level) increases to 87%. The resulting most likely ranges are 2.0–5.9

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[14] Appendix D includes an illustrative discussion and table to demonstrate the potential pitfalls of conflating or confusing GHG emissions intensity from MCONs, companies, and fields.

gCO2e/MJ (OPGEE), 3.0–3.8 gCO2e/MJ (Jacobs), 2.4–5.0 gCO2e/MJ (OPGEE + Jacobs) as indicated in Table 22.[15]

5.1.3 Major Assumptions and Limitations

The most relevant assumption is that MCONs represent country crude oil production or the specific crude oil being imported by the EU. This assumption, in particular, is relevant for those countries in which only one field data source was available. This is one of the main limitations in the analysis since the MCONs evaluated do not cover the full production of each country. For example, Figure 3 shows the comparison of GHG emissions estimates for Nigerian MCONs production. The figure shows that within a specific country there can be significant variability among individual components of GHG intensity estimates for the production of specific crudes. The variability expected in VFF GHG intensity among fields and crudes is also expected among net crude oil production GHG intensity (i.e., GHG intensity for crude oil production after accounting for exports of energy). For each crude, production GHG intensity results from the specific performance of each field, processing methods, and production practices. Adam Brandt states that "upstream emissions from petroleum production operations can vary from 3 gCO2/MJ to over 30 gCO2/MJ using realistic ranges of input parameters. Significant drivers of emissions variation are steam injection rates, water handling requirements, and rates of flaring of associated gas" (OPGEE 2013_3). The upstream GHG intensity estimates for Nigerian MCONs, shown in Figure 3, illustrate the potential variation in a country petroleum crude production (OPGEE_2). Reliable and representative upstream GHG intensity estimates for each country result from data showing the relative contributions of emissions from each field and crude oil production type.

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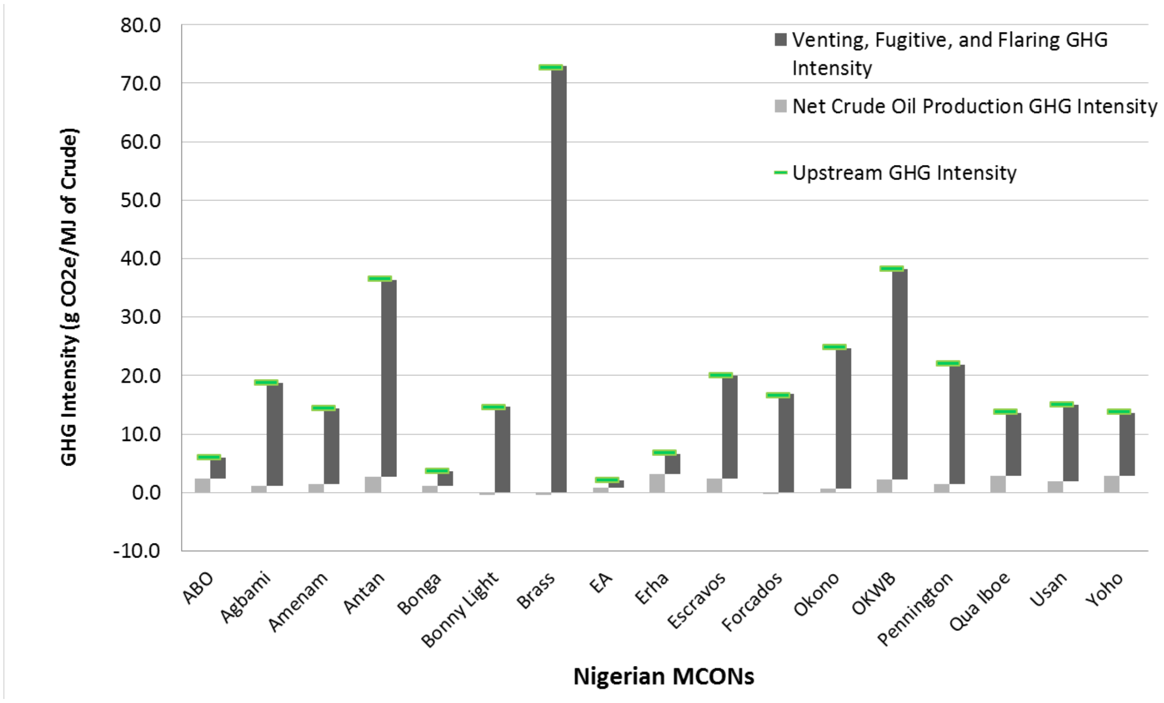
[15] Appendix E includes the list of MCONs analysed with OPGEE and the model run results for 95% flare efficiency.

Figure 3. Comparison of Nigerian MCONs Crude Oil Production GHG Intensity Estimates



The ranges among countries may cover the expected variability of crude oil production GHG intensity of the EU crude oil slate due to changes in the market for conventional crude oils. The maximum GHG intensity estimate for crude oil production from OPGEE is 24 gCO2e/MJ of crude from Venezuelan production. Crude oil production operations for the maximum value include upgrading (a point overlooked by the FQD when considering differences between extraction of conventional versus unconventional sources). On the other hand, the minimum GHG emission intensity value from OPGEE for crude oil production is -0.45 g CO2e/MJ of crude. The value is a result of the emissions allocation and substitution practice within OPGEE in which exported associated gas or onsite produced electricity offsets the emissions associated with conventional natural gas production or grid electricity. Note that these negative values from crude oil production should be considered only together with additional LCA stages including venting and flaring emissions as well as geographical location information of operations to obtain a robust interpretation of the production GHG emission intensity for a particular crude and/or field.

Another important limitation of the OPGEE + Jacobs results is that while Jacobs and OPGEE both have results for crude oil production and VFF, their assumptions and methodologies are different and result in different values for crude oil production when analysing the same crude oil. A comparison of the calculations between OPGEE and Jacobs is not feasible as Jacobs uses a proprietary model for review, but it is expected that there are differences among modeling and/or assumptions being used by OPGEE and Jacobs. ICF used Jacobs' field characterization parameters as inputs to OPGEE to compare and co-validate results from both models. However, it was not possible to replicate Jacobs' crude oil production GHG intensity estimates. As noted, the Jacobs methodology was based on a first principles bottom-up calculation and its analysis was crude-specific (see Table 16 and Table 17). ICF's assumption here is that the modeled GHG emissions intensity for crude oil production is representative of country-level crudes; it is consistent with the assumption behind using MCONs data as well as with the types of crudes Jacobs included in its study for the countries considered in this set of results.

ICF believes it is important to show the values for the OPGEE + Jacobs scenario due to the increase in country crude coverage, in addition to the OPGEE Only and Jacobs Only scenarios. The guidance above also permeates the Venting, Flaring, and Fugitives Analysis.

5.2 Venting, Flaring, and Fugitives

5.2.1 Data and Methods

Similar to Section 5.1, ICF used two sources of data, OPGEE (OPGEE v1.0) and Jacobs (Jacobs 2012), along with the same crude slate as JEC v3c and v4 to establish the VFF ranges in Table 22 and Table 23. For flaring, OPGEE sets the default value of flaring for crude oil at NOAA's national flaring average and uses a bottom-up engineering approach to account for field-specific characteristics and flaring efficiency in cases where data are available. Jacobs uses NOAA's national flaring average for every crude oil covered in the study except for select Alberta crude pathways due to the availability of third-party audited data.[16] Based on research of observed flaring efficiencies by the University of Texas (Allen 2011), model runs were performed using 90%, 95%, and 98% flaring efficiencies.

For venting and fugitives, OPGEE allows for the calculation of bottom-up engineering estimate of methane losses from various pieces of production and processing equipment. Venting estimates include emissions from the use of gas dehydrators, acid gas removal (AGR) units, compressors, gathering pipelines, and overall well workovers and cleanups. Fugitive emissions are based on factors for leakage rates of oil and gas production equipment.

Obtaining an estimate for venting and fugitive emissions for a given crude oil is difficult, as it requires knowledge of specific operations and equipment. The OPGEE model relies on data from the CARB survey of companies operating in California and API's workbook for oil and gas production equipment fugitive emissions to estimate a default value and makes relevant adjustments where possible. The Jacobs study assumes 0.2% of the associated gas is lost due to venting and fugitive emissions. While these approaches may not correctly account for highly variable global conditions, ICF uses these results to ensure consistency with Section 2.1.

OPGEE data only covers 59% of crude consumption in the EU with some missing countries contributing significant volumes to Europe (i.e., Norway, the UK, and Iran). To increase data coverage, ICF considered two approaches: 1) apply the weighted average of available countries to missing countries and extrapolate to obtain the result for the full crude stream; and 2) use data from other sources for the missing countries. ICF decided to use both methods with the OPGEE and Jacobs data and compare the

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[16] Alberta Energy Resources Conservation Board Upstream Petroleum Industry Flaring and Venting Report (ERCB ST-60b).

results. Therefore, we present three types of results: 1) calculated using only OPGEE model results; 2) calculated using only Jacobs results; and 3) calculated using both OPGEE results and Jacobs values for Norway, the UK, and Iran. Note that even with the Jacobs data, there is only 87% country data coverage and the issue of missing countries remains; therefore, some results were still extrapolated. This is the same methodology used to estimate GHG intensity for crude oil production. Mixing data sources may not ensure consistency but has the benefit of more geographical coverage.

5.2.2 Results

Table 23 shows the estimated most likely ranges of 3.8–11 gCO2e/MJ (OPGEE), 2.7–3.7 gCO2e/MJ (Jacobs), and 2.9–7.9 gCO2e/MJ (OPGEE + Jacobs). Overall, the estimates for venting, flaring, and fugitive emissions are significantly higher than the JEC's estimates. This is largely a result of the sensitivity on flaring efficiency where the lower end of the range is based on a 98% flare efficiency and the upper end is based on a 90% flare efficiency. The JEC estimates include a 98% flare efficiency. The results for 95% flaring are shown in the column labeled "average."[17] In addition, the OPGEE model performs a bottom-up calculation of venting and fugitive emissions, which also increases the GHG intensity of the OPGEE Only and OPGEE + Jacobs ranges.

The CanmetENERGY, Jacobs, and KPMG reports use a crude-specific approach to estimate VFF; for this reason, the range of values in these reports may not be comparable directly to ICF's or JEC's but may be useful for reference. The Jacobs report looks at 12 crudes from around the world with venting and flaring emissions ranging from 0.26 gCO_2e/MJ (UK's Mariner crude) to 10.26 gCO_2e/MJ (Nigeria's Bonny Light crude). The CanmetENERGY report, which uses an engineering model to estimate a national average of flaring emissions from Canada, Russia, Nigeria, Iran, and Iraq, shows 0.8 gCO_2e/MJ (Canadian crude) to 5.27 gCO_2e/MJ (Nigerian crude). The CanmetENERGY report covers flaring only and thus has lower emission figures than the national averages cited in Table 22.

5.3 Crude Oil Transport

5.3.1 Data and Methods

The OPGEE model was used to calculate GHG emissions for the transport stage (OPGEE v1.0). Transport emissions were calculated for crude oil transport to European refineries from the top 20 oil producers that supply the EU listed in JEC v3c Table 3.1.1-3. Minimum, maximum, and average emissions were calculated for the pipeline, shipping, and total emissions.

ICF determined inputs into the OPGEE model for shipping and pipeline emissions from crude production locations to European refineries. Minimum, maximum, and average shipping pipeline distances were determined using a combination of US EIA country analyses, Portworld[18], and the OPGEE model (OPGEE 2013_2). In each case, the closest or most likely port was selected as the point of origin. In terms of the destination port, the farthest and closest European destination ports were selected for each crude oil to determine the minimum and maximum shipping distances and fully bound the crude oil transport

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[17] Appendix E includes the list of MCONs analysed with OPGEE and the model run results for 95% flare efficiency.

[18] Portworld, Distance Calculator http://www.portworld.com/map/

range. ICF notes that it is possible that the selected destinations are not typical of the origin production field or country and may not be typical terminals for crude oil shipments. The values for the distances can be found in Appendix A.

Many of Europe's top 20 oil supply countries use pipelines to transport crude oil from the reservoirs to the shipping terminals. Pipeline distances were obtained from or estimated by information from two main sources: pipeline distance data listed in the OPGEE model (OPGEE 2013_2) and US EIA country analysis. In the case where the origin country had only one reservoir, the minimum, maximum, and average pipeline distances were all equal. Where there was more than one reservoir within the origin country, the minimum and maximum pipeline distances were selected based on reservoir location in relation to the most likely export terminal; a weighted average was then calculated (weighted on oil production volume or capacity by reservoir) for the "average" pipeline distance.

ICF determined emission factors for shipping by using a 200,000-tonne tanker. ICF notes that some origin terminals would be able to handle (and would therefore use) tankers up to 500,000 tonnes, but many would not be able to handle even a 200,000-tonne tanker and would therefore be using smaller tankers. Those that use larger tankers would have lower emissions per tonne-km and those that use smaller tankers would have higher emissions per tonne-km when compared with the 200,000-tonne tanker selected for this analysis. The following OPGEE assumptions were used to determine the transport emissions from the calculated distances:

- 100% of ships are fuelled by residual oil
- 45% of pipeline equipment (e.g., pumps and compressors) are fuelled by diesel, 55% of equipment are fuelled by natural gas
- Electricity was not considered as an energy source for pipeline equipment

This analysis only considers crude oil transport by pipeline and tanker. ICF notes that other modes of transport for crude oil may be used, including rail and barges, but these are not considered here.

In this analysis, ICF has estimated minimum, maximum, and average crude oil transport emissions for each of Europe's top 20 oil supply countries. To estimate the overall emissions value for European crude oil transport, an average weighted by annual country production was calculated. Considering all countries of origin and all destination ports, the minimum and maximum ranges for pipeline transport, tanker transport, and total transport are shown in Table 22.

This analysis indicates that there is a large range of crude oil transport emissions, depending on a variety of factors, such as reservoir location, destination port, transport mode, etc. Given the variability of the possible crude oil transport pathways (including distance, transport mode, energy source, etc.) from each reservoir within each origin country to the numerous European refineries, the calculated transport emissions values presented in this report should be viewed as approximate estimates within a large range of possible transport emissions. .

Similar to the OPGEE model, the Jacobs report considered pipeline and tanker transport of crude oil from a production field to a European refinery. In calculating the crude oil transport GHG emissions, the Jacobs report considered transport distances, cargo capacities, and transport modes (and associated emission factors).

5.3.2 Results

Based on the transport distances listed in Appendix B, the OPGEE model computes a most likely range of 0.29-1.2 gCO2e/MJ (Table 22). The Jacobs most likely range is 0.27-1.2 gCO2e/MJ and the resulting OPGEE + Jacobs most likely range is 0.29–1.2 gCO2e/MJ.

The ICCT report only considers tanker transport of crude oil from the producer country terminal to a European refinery (refineries not specified). The discussion within the ICCT report indicates that transport distances are determined on a reservoir basis. However, because the ICCT analysis only considers tanker transport, it only considers distance from a gathering station (not a specific reservoir) to Europe. Crude oil transport by pipeline is not taken into consideration, even though according to the OPGEE analysis and the Jacobs report, pipeline transport can account for a large share of the total transport emissions when pipelines are the primary transport mode (e.g., pipeline transport from Russia to Europe). For this reason, the ICCT report was not included in the analysis.

5.4 Crude Oil Refining

5.4.1 Data and Methods

The basis for the estimated most likely range GHG intensity from European refining was established using the CONCAWE assessment of current and projected operations (CONCAWE 2007). The results are based on actual reported European refinery throughput, product mix, and emissions, and not on projections. The figures referenced in the following section can be found in Appendix C.

CONCAWE reported that actual CO2 emissions in 2005 were slightly above 0.20 t CO2/t crude (CONCAWE 2007, Figure 14a). Updating this to 2010, emissions are estimated to be about 0.21 t CO2/t crude. This estimate was based on a historic 10% increase in energy consumption and a corresponding 10% increase in energy efficiency from 1990 to 2010 (CONCAWE 2012, Figure 4). Assuming similar efficiency improvements and energy use, a 5% increase in energy and emissions between 2005 and 2010 was estimated.

The 0.21 t CO2/t crude estimated (CONCAWE 2007) is equivalent to approximately 4.7 gCO2/MJ of crude (based on a crude energy content of 5.8 million Btu/barrel and a crude oil specific gravity of 0.86[19], API 2009).

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[19] 0.86 is representative of 34 API crude

The estimated most likely range for emissions corresponds reasonably well with the Jacobs report, using 34° API, which is the basis for the JEC refinery estimate (Jacobs 2012, Figure 1-14). The 4.7 gCO2/MJ is near the average of low and high conversion refineries at that API gravity.

Allocation of energy and emissions to specific products is based on the relative mix of products by economic value. Table 19 shows data from the CONCAWE report for the product mix in 2005 (CONCAWE 2007, Figure 2). This simplistic allocation methodology was employed due to limited data and model availability; the models used in the JEC and Jacobs reports are proprietary and confidential. With access to a linear programming refinery model of the EU refining complex, a more robust, detailed, and complex analysis and allocation methodology could be applied. Allocation of the energy requirements for the different refinery processes could be applied to the set of products based on the various unit operations (FCC, vacuum distillation, etc.) required for each product. The energy required would be based on the feedstock crude oil. For example, with heavier crude oils, more energy would be required for the same product slate due to an increased energy requirement for primary fractionation and production of lighter products.

Table 19. EU Refinery Product Slate by Energy and Weight Percent

FUEL	Weight (%)[20]t[1]	LHV (J/M3)[21]	Kg/M3[22]	Energy (%)
LPG	4%	2.41E+10	506	4.5
Special Naphtha	7%	3.31E+10	774	7.0
Gasoline	18%	3.31E+10	742	18.8
Jet Fuel/Kerosene	7%	3.57E+10	816	7.2
Diesel	25%	3.67E+10	847	25.4
Other Gasoils	17%	3.97E+10	950	16.7
Other Bottoms	22%	3.96E+10	993	20.6

5.4.2 Results

Estimates of the product specific emissions were made assuming products of economic value. The resulting GHG intensity are shown in Table 20.

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[20] CONCAWE 2007, Figure 2

[21] API 2009.

[22] Ibid

Table 20. Scenarios for the GHG Intensity of Refined Products by Economic Value

Economic Value Products	Percent of Total Energy	GHG Intensity
Gasoline + Diesel	44.2%	10.6
Gasoline + Diesel + Jet/Kerosene	51.3%	9.1
Gasoline + Diesel + Jet/Kerosene + Naphtha	58.4%	8.0
Gasoline + Diesel + Jet/Kerosene + Naphtha + Other Gasoils	75%	6.3
All Products	100%	4.7

All the products in each row of Table 20 were allocated the same GHG emissions on an energy basis; thus, they all have the same GHG intensity. ICF reviewed the refining sections of the reports by JEC and Jacobs and found they had differing results, as shown in Table 21. Without access to their propriety LP refinery models, ICF could not determine whether gasoline or diesel should result in a higher GHG intensity and chose to assign them the same emissions. ICF determined the most likely range for oil refining GHG intensity to be 6.3–9.1 gCO2e/MJ. This is due to determination that not all products have economic value

The above most likely range for oil refining GHG intensity is in line with the estimates from JEC (JEC v3c and 4) and Jacobs (Jacobs 2012), as noted in Table 21.

Table 21. Comparison of GHG Intensity Values for Refining

	JEC	Saudi Arabia FCC-Ckr	Saudi Arabia FCC-VB	Russia FCC-VB	NorthSea1 FCC-VB
Diesel (gCO2eq/MJ)	8.6	8.6	8	7.5	6.5
Gasoline (gCO2eq/MJ)	7	9.5	9.1	9.1	7.9

The predicted emission allocations based on the CONCAWE report appears to agree fairly well with the emissions estimates from JEC and Jacobs. Due to limited data and model availability, refinery crude oil loses were not taken into account.

5.5 Estimated Most Likely Range

Table 22 below shows the results of the analysis performed for the crude oil production, venting, flaring, and fugitives, and crude oil transport stages. The well-to-refinery gate values in the last three columns aggregate the averages, maximums, and minimums for each country. The weighted average results are based on the coverage of crude data available, which extrapolates the average calculated value for the available countries to the missing countries. The OPGEE Only analysis only has 59% coverage, Jacobs Only has 78.5% coverage, and OPGEE + Jacobs increases the coverage to 87.1%. The negative value for Nigeria is a result of the disaggregation of OPGEE results and a crediting methodology for sales of associated gas production. As indicated in Section 5.1.3, negative values for the GHG intensity of crude oil production (and in general any offsite offset credits in a life cycle analysis) should be considered in conjunction with additional information (e.g., venting and flaring emissions and geographical location of operations) to obtain an appropriate interpretation of the production GHG intensity. The WTW GHG intensity is the combination of the well-to-refinery gate range, refining range, finished product transport stage and combustion (TTW).

Table 22. Results for the Production, Venting, Flaring, and Fugitives, and Transport Stages

Country	%crude	Production			Venting, Flaring and Fugitives			Transport			Well to Refinery Gate Total		
		Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
OPGEE													
Russia	27.4%	2.91	1.41	8.06	5.58	4.02	8.03	0.51	0.22	1.89	9.00	5.66	17.98
Libya	9.3%	2.92	2.92	2.92	7.86	6.78	9.67	0.35	0.21	0.49	11.13	9.91	13.08
Saudi Arabia	5.3%	3.77	3.55	3.92	1.91	1.80	2.09	1.18	0.24	2.05	6.86	5.59	8.06
Nigeria	3.8%	1.33	-0.45[1]	3.08	16.91	1.18	73.01	0.57	0.5	0.64	18.81	1.23	76.73
Azerbaijan	3.6%	2.39	2.39	2.39	1.81	1.75	1.90	0.77	0.32	1.01	4.96	4.46	5.30
Iraq	2.9%	4.10	4.10	4.10	6.02	1.93	7.33	1.22	0.65	1.78	11.34	6.67	13.20
Angola	1.5%	2.13	1.65	2.38	4.42	3.53	5.59	0.6	0.49	0.7	7.15	5.68	8.67
Mexico	1.2%	4.11	4.11	5.85	2.10	3.70	2.79	0.73	0.61	0.9	6.94	8.42	9.54
Algeria	1.2%	2.46	2.46	2.46	6.01	5.25	7.28	0.37	0.26	0.49	8.84	7.97	10.23
Venezuela	0.9%	7.12	1.87	23.97	3.21	1.72	4.05	0.63	0.47	0.75	10.96	4.06	28.77
Brazil	0.8%	2.56	1.20	4.98	2.03	1.57	2.84	0.66	0.55	0.77	5.25	3.32	8.59
Kuwait	0.6%	3.75	3.75	3.75	2.14	2.02	2.34	1.19	0.62	1.75	7.08	6.39	7.84
Congo	0.5%	2.60	2.59	5.42	6.87	5.89	8.57	0.62	0.51	0.73	10.09	8.99	14.72
Jacobs													
Russia	27.4%	3.88	2.81	4.95	4.76	4.19	5.70	0.51	0.22	1.89	9.15	7.22	12.55
Norway	14.4%	3.16	3.16	3.16	0.50	0.48	0.54	0.29	0.16	0.41	3.95	3.80	4.11
Libya	9.3%	2.70	2.70	2.70	3.00	2.67	3.53	0.35	0.21	0.49	6.05	5.59	6.72
Saudi Arabia	5.3%	2.97	2.97	2.97	0.84	0.79	0.93	1.18	0.24	2.05	4.99	4.00	5.95
UK	8.6%	3.47	3.00	3.93	0.38	0.26	0.52	0.32	0.23	0.4	4.17	3.49	4.85
Iran	5.1%	2.64	2.64	2.64	3.72	3.32	4.39	1.29	0.61	1.97	7.65	6.57	8.99
Nigeria	3.8%	3.51	3.51	3.51	8.62	7.70	10.16	0.57	0.5	0.64	12.70	11.71	14.31
Iraq	2.9%	2.99	2.99	2.99	5.41	4.84	6.37	1.22	0.65	1.78	9.62	8.48	11.13
Brazil	0.8%	3.80	3.80	3.80	1.05	0.99	1.14	0.66	0.55	0.77	5.51	5.35	5.71
Venezuela	0.9%	5.85	5.85	5.85	1.47	1.31	1.74	0.63	0.47	0.75	6.51	6.19	6.90
No Data													
Kazakhstan	4.5%							0.83	0.64	1.10			
Denmark	1.9%							0.25	0.06	0.45			
Syria	1.3%							0.35	0.11	0.58			
Egypt	0.8%							0.32	0.18	0.47			
Other	4.4%												
Weighted Average Results													
OPGEE Only	59.0%	3.0	2.0	5.9	5.9	3.8	11	0.57	0.29	1.2	9.5	6.1	18
Jacobs Only	78.5%	3.4	3.0	3.8	3.1	2.7	3.7	0.56	0.27	1.2	7.0	6.0	8.7
OPGEE + Jacobs	87.1%	3.0	2.4	5.0	4.4	2.8	8.0	0.57	0.29	1.2	8.0	5.5	14
JEC v3c		1.5			2.8			0.8			5.1		

🟩 Jacobs Values
🟨 No Values from Jacobs or OPGEE
🟦 95.6% of Crude

Notes: 1—The negative value is a result of the disaggregation of OPGEE results and its crediting methodology for sales of associated gas production.

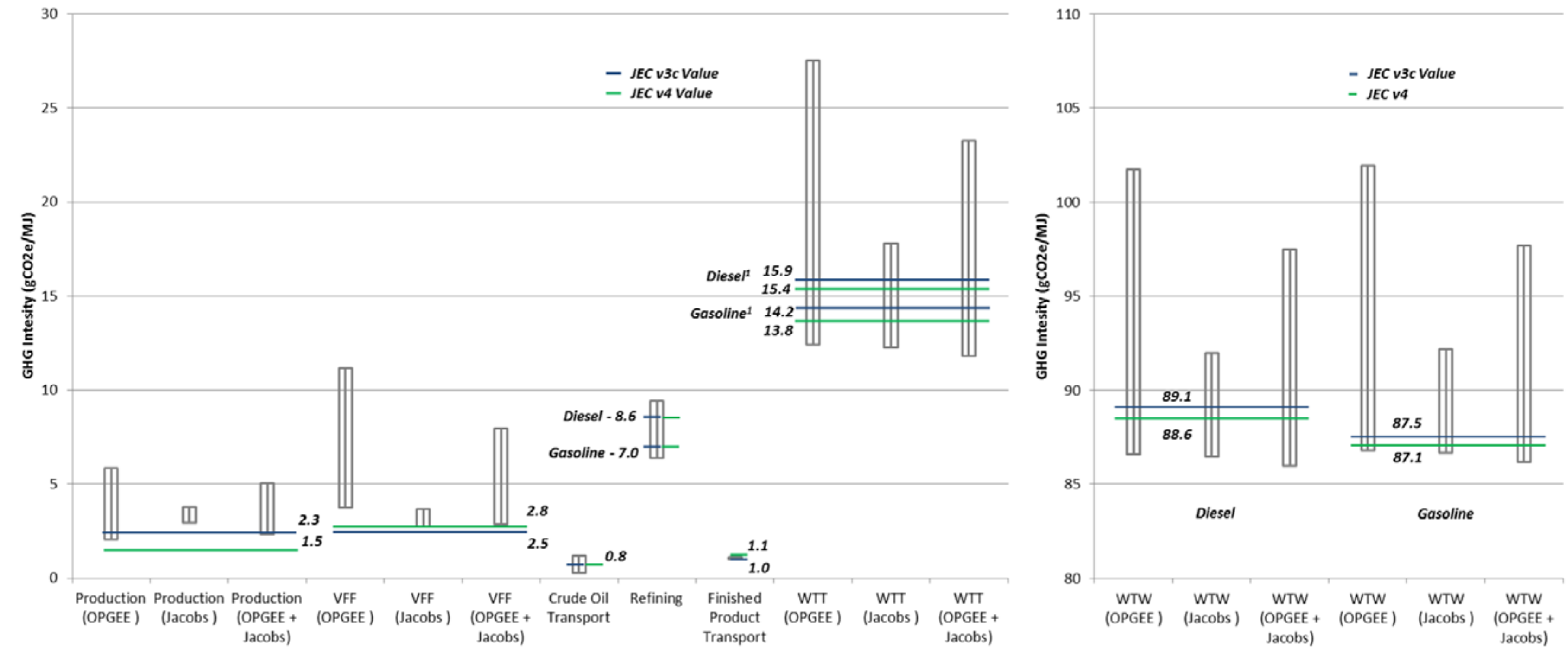
Table 23. Comparison of JEC Report and the Estimated Most Likely Range

LCA Stage[3]		JEC v3c Values	JEC v4 Values	Most Likely Range
Crude Oil Production (crude)	OPGEE	2.3	1.5	2.0–5.9
	Jacobs			3.0–3.8
	OPGEE + Jacobs			2.4–5.0
VFF (crude)	OPGEE	2.5	2.8	3.8–11
	Jacobs			2.7–3.7
	OPGEE + Jacobs			2.9–7.9
Crude Oil Transport (crude)		0.8	0.8	0.27–1.2
Refining		8.6 (diesel) 7.0 (gasoline)	8.6 (diesel) 7.0 (gasoline)	6.3–9.1
Finished Product Transport[1]		1.0	1.1	1.0
WTT[2]	OPGEE	15.9(diesel) 14.2 (gasoline)	15.4 (diesel) 13.8 (gasoline)	12.4–27.5
	Jacobs			12.3–17.8
	OPGEE + Jacobs			11.7–23.2
TTW[1]		73.2 (diesel) 73.4 (gasoline)	73.2 (diesel) 73.4 (gasoline)	73.2 (diesel) 73.4 (gasoline)
WTW	OPGEE	89.1 (diesel) 87.5 (gasoline)	88.6 (diesel) 87.1 (gasoline)	86.6-101.7 (diesel) 86.8-101.9 (gasoline)
	Jacobs			86.5-92.0 (diesel) 86.7-92.2 (gasoline)
	OPGEE + Jacobs			86.0-97.4 (diesel) 86.2-97.6 (gasoline)

Notes: 1 – Finished Product Transport and TTW values were not analyzed as there is general consensus in the scientific community on carbon intensity for these stages.
2 – The individual stages are not additive for the JEC values due to crude energy loss during the refining stage.
3– For Crude Oil Production, Venting, Flaring, and Fugitives, and Crude Oil Transport, GHG intensity is for crude oil (crude), the remaining categories are for finished products (gasoline and diesel)

The values in Table 23 are shown graphically in Figure 4. The boxes designate the estimated most likely range. The range takes into account countries that have data available for multiple fields and MCONs and a flaring efficiency range of 90-98%. The upper bounds are based on the more GHG-intensive crude oils within a country with multiple crudes and the lower (90%) flare efficiency, and the lower bounds are based on the lower GHG-intensive crude oils within a country and a higher flare efficiency (98%). The GHG intensities from the JEC reports for each stage are not directly included with the refining and finished product stages because the JEC report assumes gasoline and diesel have an 8% and 10% crude energy loss, respectively (JEC v3c and v4). The crude energy loss represents crude consumed within the refinery for energy production.

Figure 4. Comparison of JEC Report and the Estimated Most Likely Range



Note: 1 – JEC individual stages are not additive to the WTT value due to crude energy loss during the refining stage

For comparison, Table 23 shows the JEC values for each stage. For crude oil production and venting, flaring, and fugitives, the JEC values are at the bottom of or below the most likely ranges. For crude oil transport and refining, the JEC GHG intensities fall within most likely range.

As stated in Section 5.4, the analysis for the most likely refining range is based on a simplistic allocation analysis. The JEC values for the WTT GHG intensity fall within the most likely range, but at the low end of the OPGEE Only and OPGEE + Jacobs mostly likely ranges, and within the middle of the Jacobs Only range.

Similar to the deficiencies of the OGP data, there are still significant gaps within the coverage of data used for this analysis. The MCONs used for the analysis do not fully cover all of the crude oil produced within each country and are not necessarily the same MCONs imported to the EU. A more complete analysis would gather MCON-level data for EU crude oil imports and corresponding data for inputs into the OPGEE model for MCONs that are not currently covered.

6 Conclusion

The FQD's proposed implementing measure assigns default GHG intensity values to crude oils in each of three main categories of feedstock: conventional crude oil, oil shale, and natural bitumen. Per the draft Commission Directive (EC 2011), the gasoline and diesel GHG intensity values should be "based on the average default greenhouse gas intensity values." GHG intensities intended to meet this requirement should come from an LCA based on data for the main crudes consumed in the EU and based upon the best available data and methodologies. The JEC reports produce GHG intensities for marginal gasoline and diesel, not the average of all crude feedstocks.

Based on the analysis of this report, the JEC studies do not achieve the most accurate representation of life cycle crude GHG emissions needed to determine the average EU gasoline and diesel GHG intensities. Major deficiencies in their approach include: using data sources such as OGP that aggregate emissions over an entire region; voluntary data submissions that only cover 4% of crude oil production in some regions; and data that include combined energy and emissions for crude oil and natural gas production. These data sources do not meet the standards of the key design elements for reliability, accuracy, vintage, and quality (Table 3). There are currently more up-to-date and accurate data and methodologies available (e.g., OPGEE). The JEC analysis used a combination of average (crude oil production and venting, flaring, and fugitives) and marginal (crude oil transport and refining) methodologies when a full average methodology should be used.

Using available models and studies, ICF estimated a most likely range for average gasoline and diesel GHG intensities. The estimated diesel ranges for the three sets of data are 86.6–101.7 gCO2/MJ (OPGEE), 86.5-92.0 gCO2e/MJ (Jacobs), and 86.0-97.4 gCO2e/MJ (OPGEE + Jacobs). The estimated gasoline ranges for the three sets of data are 86.8–101.9 gCO2/MJ (OPGEE), 86.7-92.2 gCO2e/MJ (Jacobs), and 86.2-97.6 gCO2e/MJ (OPGEE + Jacobs). Consistent with numerous LCAs for conventional crude oil, these results indicate that there is a spectrum of crude oil GHG intensities and the estimated most likely range is large. Increased granularity and drivers for better crude information in the data collected for EU crude oil imports in terms of field source or MCON would allow for the narrowing of this range. A more complete analysis would gather MCON level data for EU crude oil imports and corresponding data for inputs into the OPGEE model for MCONs that are not currently covered. This report demonstrates that assumptions, research methodology, and data quality can result in GHG intensity differences of at least 3-4 gCO2e/MJ, equivalent to 50-75% of the 6% GHG intensity reduction standard.

The following are recommendations for a more accurate LCA based on the analysis of this study:

- Due to the spectrum of crude oil GHG intensities, accurate LCA modeling needs to differentiate and evaluate GHG intensities for each crude oil individually (including natural bitumen and oil shale feedstock crude oils). The result of such modeling would be more representative of the actual gasoline and diesel GHG intensity.
- The most recent public, transparent, verifiable, and reproducible data and models (such as OPGEE) should be used to determine the individual crude oil GHG intensities. The data and models should

be able to determine crude oil specific (e.g., by Marketable Crude Oil Name (MCON) or field) GHG intensities.

- LCA modeling should determine the average gasoline and diesel GHG intensity for refining in 2010 using the EU 2010 set of crudes and total EU refining emissions and apply this value to all crude oil feedstocks. The chosen allocation or substitution methodology needs to be transparent.

Appendix A: OGP Environmental Data Form

PAGE 1 OF 2: OGP ENVIRONMENTAL DATA FORM - 2012 DATA

Year:	
Contact name:	

Company:	
Country:	

Are data relating to support and standby vessels included (Y/N)?

---

1. GROSS PRODUCTION

in 10^3 tonnes

IMPORTANT: Data relating to LNG production must be reported separately to data relating to hydrocarbon production.
LNG related data must be reported on an entirely separate spreadsheet

HYDROCARBONS	**Liquids**	**Gas**	**Total**
Onshore			
Offshore			
Unspecified			
Total			

OR

LNG

---

2. ATMOSPHERIC EMISSIONS

Indicate whether ethane is included with NMVOC emissions (yes/no):

Estimation Methodology used: **OGP TIER No.** **API** **Other (state)**

A. ONSHORE

	CH_4 (t)	**NMVOC (t)**	**SO_2 (t)**	**NO_x (t)**	**CO_2 (t)**
Energy					
Flare					
Vents					
Fugitive losses					
Other/Unspecified E&P					
Total E&P					

B. OFFSHORE

	CH_4 (t)	**NMVOC (t)**	**SO_2 (t)**	**NO_x (t)**	**CO_2 (t)**
Energy					
Flare					
Vents					
Fugitive losses					
Other/Unspecified E&P					
Total E&P					

C. UNSPECIFIED

Incl. flared/vented	**CH_4 (t)**	**NMVOC (t)**	**SO_2 (t)**	**NO_x (t)**	**CO_2 (t)**
Energy					
Flare					
Vents					
Fugitive losses					
Other/Unspecified E&P					
Total E&P					

NB: Emissions from support vessels and standby vessels should not be included unless they cannot be separated out.

---

3. PRODUCED WATER DISCHARGES

	Produced water discharged (m^3)	**Oil discharged in produced water (t)**	**Water reinjected (m^3)**	**Evaporation ponds (m^3)**
A. ONSHORE				
B. OFFSHORE				
C. UNSPECIFIED				

PAGE 2: OGP ENVIRONMENTAL DATA FORM - 2012 DATA

Year:		**Company:**	
Contact name:		**Country:**	

4. NABF RETAINED ON DRILL CUTTINGS DISCHARGED TO THE SEA (t) - OFFSHORE ONLY

Indicate whether NABF discharge data are available (yes/no):

	Y/N
GROUP I	
GROUP II	
GROUP III	
Unspecified	

	TONNES
GROUP I	
GROUP II	
GROUP III	
Unspecified	
Total	

VOLUME OF CUTTINGS GENERATED WHERE NABF ARE USED (M^3):

5. OIL SPILLS in bbl

State minimum spill size recorded (bbl):

Incident details for spills 10-100 bbl should be reported using the SPILL DETAILS worksheet

Incident descrptions for larger spills (>100 bbl) should be reported using the SPILL_DESCRIPTION worksheet

		Onshore		Offshore	
		Number	**Quantity (bbl)**	**Number**	**Quantity (bbl)**
Oil spills	<1 bbl				
	1-10 bbl				
	10-100 bbl				
	>100 bbl				
	Unspecified (excl. spills <1bbl)				
	Total	0	0	0	0
Chemical & other spills	<1 bbl				
	>1 bbl				
	Unspecified (excl. spills <1bbl)				
	Total	0	0	0	0

6. ENERGY CONSUMPTION

	On site combustion (GJ)	Purchased (GJ)	Unspecified (GJ)	Total (GJ)
A. ONSHORE				
B. OFFSHORE				
C. UNSPECIFIED				

NB: Energy from terminals should be categorised by source of production not the location where energy used.

7. HYDROCARBONS FLARED (excluding vented)

Indicate which you are reporting here using the check box to right: **Total Flared** ☐ **HCs Flared** ☐

Mass HCs flared or total flare mass if HC flare not available (thousand tonnes)	**HC Flared (10^3 t)**

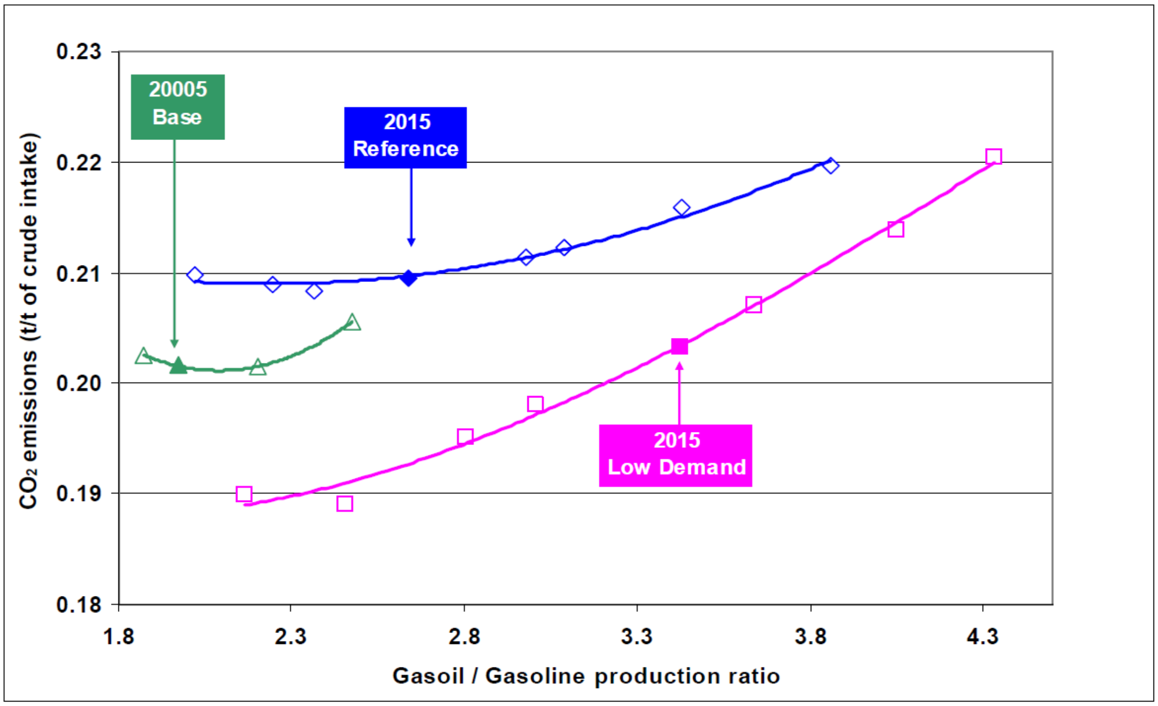
The following conversion factors may be applied in section 7 above:
1000 m^3 of associated gas = 1.00 t
1000 ft^3 of associated gas 28.3 m3 = 0.0283 t

Appendix B: Crude Oil Transport Distance Inputs to OPGEE

	Pipeline Distance				Shipping Distance (source: www.portworld.com/map/)						
Country of Origin	Min. (Mile)	Max. (Mile)	Avg. (Mile)	Source	Min. (Mile)	Origin	Destination	Max. (Mile)	Origin	Destination	Avg. (Mile
Russia	140	2900	338	OPGEE	1430	St. Petersburg	Rotterdam, Netherlands	4848	St. Petersburg	Trieste, Italy	3139
Norway	200	200	200	EIA http:	590	Bergen	Rotterdam, Netherlands	2825	Bergen	Fos, France	1708
Libya	300	300	300	OPGEE	573	Tripoli	Naples, Italy	3010	Tripoli	Bremerhaven, Germany	1792
UK	400	400	400	EIA http:	452	Falmouth	Rotterdam, Netherlands	1934	Falmouth	Fos, France	1193
Saudi Arabia	0	400	267	OPGEE	2126	Yanbu	Trieste, Italy	16288	Yanbu	Trieste, Italy	9207
Iran	50	550	300	http://w	5107	Kharg Island	Trieste, Italy	14949	Kharg Island	Trieste, Italy	10028
Kazakhstan	940	1384	1066	http://w	1837	Novorossiysk, Russia	Trieste, Italy	4130	Novorossiysk, Russia	Rotterdam, Netherlands	2984
Nigeria	100	100	100	OPGEE	3901	Limbe, Cameroon	Sines, Portugal	5131	Limbe, Cameroon	Rotterdam, Netherlands	4516
Azerbaijan	520	1100	1027	http://w	730	Iskenderun, Turkey	Piraeus, Greece	4414	Trabzon, Turkey	Bremerhaven, Germany	2572
Iraq	100	100	100	OPGEE	5227	Kuwait	Trieste, Italy	15067	Kuwait	Trieste, Italy	10147
Denmark	0	0	0	http://w	491	Skagen	Rotterdam, Netherlands	3910	Skagen	Trieste, Italy	2201
Angola	0	0	0	OPGEE	4228	Off-Angola	Sines, Portugal	6137	Off-Angola	Trieste, Italy	5183
Syria	60	250	155	http://w	730	Iskenderun, Turkey	Piraeus, Greece	4106	Iskenderun, Turkey	Bremerhaven, Germany	2418
Mexico	0	100	0	OPGEE	5290	Coatzacoalcos	Sines, Portugal	7428	Coatzacoalcos	Trieste, Italy	6359
Algeria	500	500	500	OPGEE	260	Algiers	Valencia, Spain	2253	Algiers	Bremerhaven, Germany	1257
Venezuela	50	130	127	OPGEE	3940	Puerto la Cruz	Sines, Portugal	6020	Puerto la Cruz	Trieste, Italy	4980
Brazil	0	0	0	OPGEE	4814	Rio de Janeiro	Sines, Portugal	6732	Rio de Janeiro	Trieste, Italy	5773
Egypt				http://w	1585	Suez	Trieste, Italy	4068	Suez	Bremerhaven, Germany	2827
Kuwait	50	50	50	OPGEE	5227	Kuwait	Trieste, Italy	15067	Kuwait	Trieste, Italy	10147
Congo	0	0	0	OPGEE	4440	Luanda, Angola	Sines, Portugal	6349	Luanda, Angola	Trieste, Italy	5395

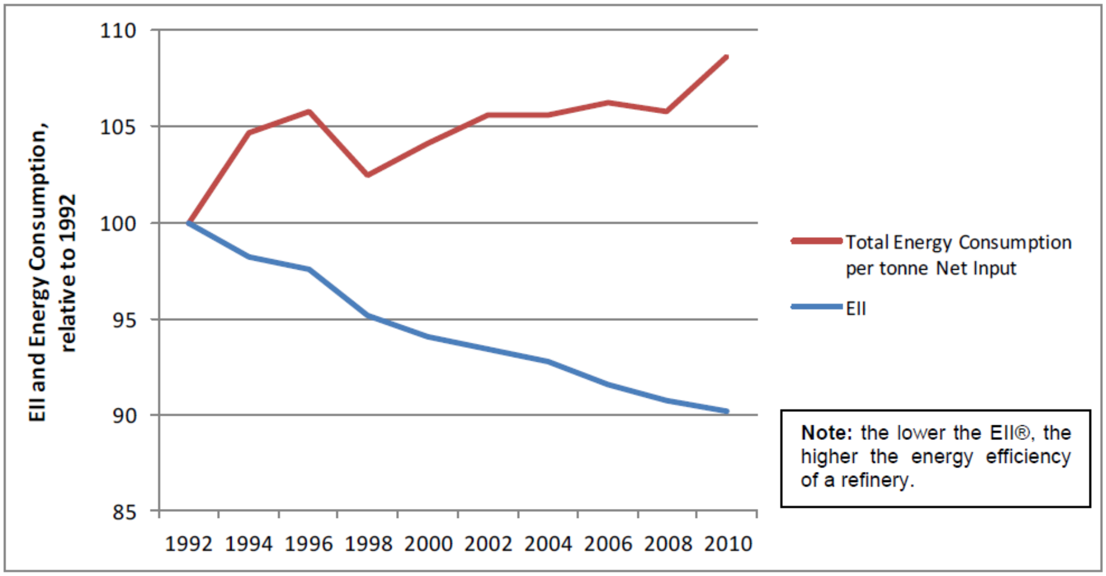
Appendix C: Section 5.4 Figures

Figure 14a Specific CO_2 emissions$^{(1)}$



(CONCAWE 2007)

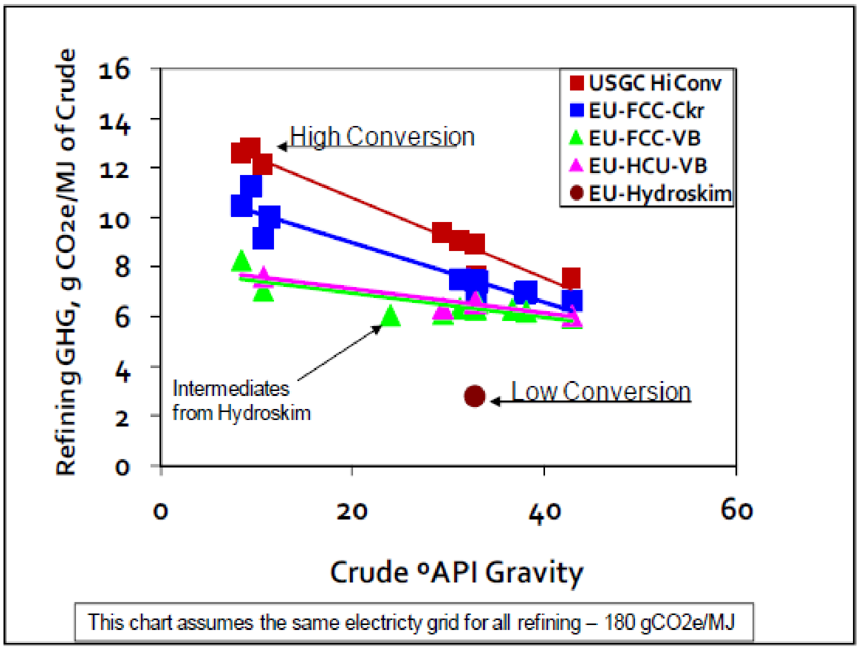
Figure 4 EU refineries energy consumption and efficiency trends relative to 1992
(Source: Solomon Associates)



Note: the lower the EII®, the higher the energy efficiency of a refinery.

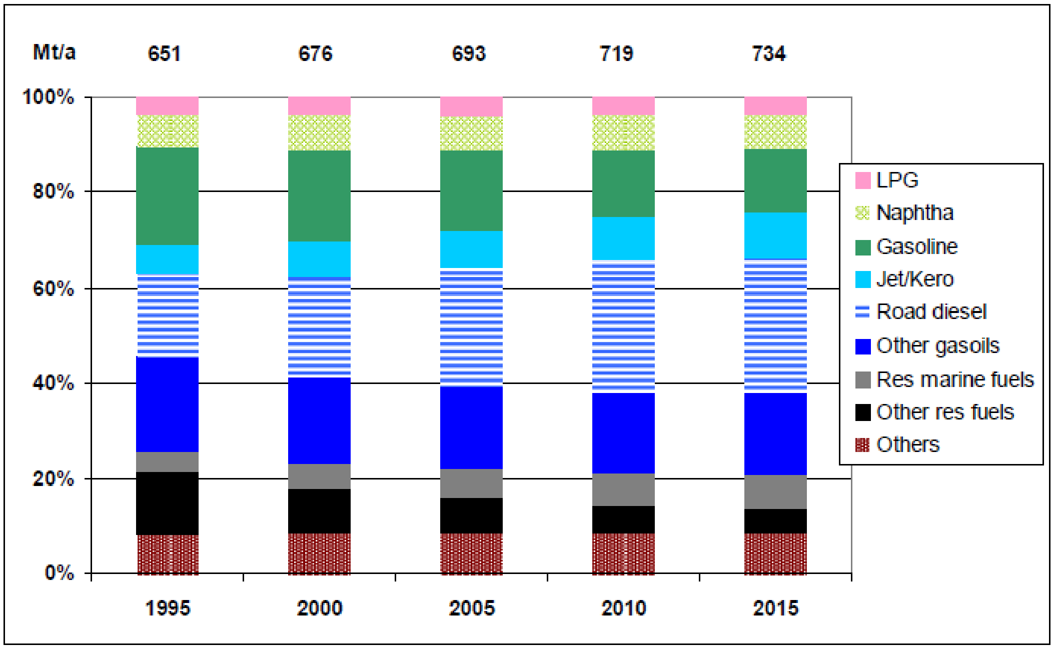
(CONCAWE 2012)

Figure 1-14.
Energy Consumption in Refining



(Jacobs 2012)

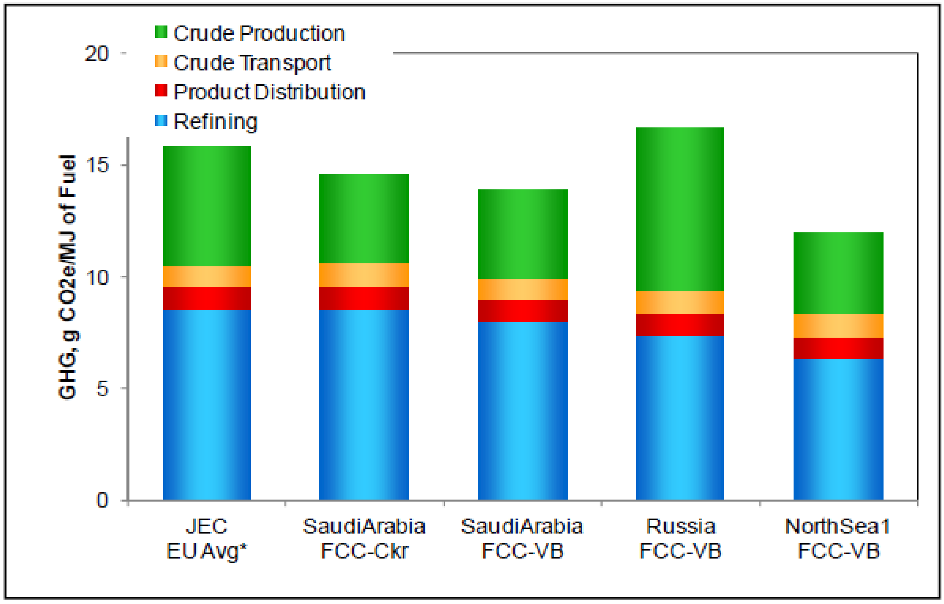
Figure 2 Historical and forecast product demand (EU-25+2)



(Source: Wood Mackenzie)

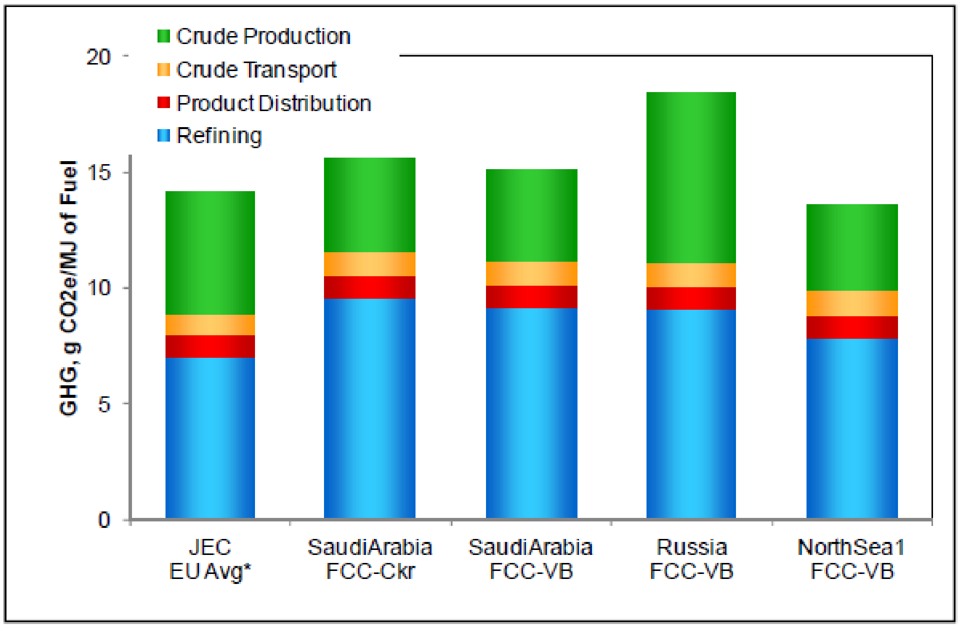
(CONCAWE 2007)

Figure 1-34.
Diesel - WTT Carbon Intensity Comparison to JEC Results



(Jacobs 2012)

Figure 1-35.
Gasoline - WTT Carbon Intensity Comparison to JEC Results



**JEC: JRC, EUCAR, CONCAWE Average EU refinery and average crude results from: JRC - WTT Report v3c July 2011 – Appendix 2*

(Jacobs 2012)

Appendix D: Illustrative Discussion of Potential Pitfalls of Confusing MCONs, Companies, and Fields

The table below illustrates the limitations of using public data to represent country level GHG emissions. The table shows deviations in GHG estimates due to selection of field specific GHG estimates versus GHG estimates accounting for the relative contribution of each field in crude oil production. [23] For example, the table indicates that in the absence of data, the use of information for the operations of a particular company or field such as Pan Ocean to represent emissions for all of Nigeria would overestimate the country GHG emissions intensity estimate by about a factor of 3 for crude oil production, 39% for VFF, and 57% for the total upstream emissions. For the three countries included in the table, the average deviation between field GHG emissions and estimated country GHG intensity is 57%. Also, the deviations could be as low as 2% or as high as 276% for crude oil production (1% to 427% for VFF and 0 to 382% for total upstream emissions) depending on which country and which field the data represents.

This limitation is also applicable at the crude level. For example, without information about the relative contribution of each field or company in blending a crude, the GHG emissions estimated based on overall field performance composition could be under- or over-estimated. In the case of Bony Light, for instance, the GHG emissions intensity estimated for crude oil production of -0.35 gCO2e/MJ of crude is based on companies' production and contribution would be increased by more than a factor of four. ICF calculated a value based only on field of origin and field production. The variation and standard deviation in the estimates shown in the table below are inconsistent with the criteria of a rigorous lifecycle analysis that ICF has identified in this report. Literature in the field of life cycle assessment suggests that standard deviations for variation in emissions range from a typical 20% (when assessing existing technologies and processes) up to 100% for estimating less certain technologies (e.g., emerging technologies and processes). [24] These figures highlight the need for clear documentation of data sources used to conduct lifecycle analyses and report results.

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[23] Deviation as a percentage is defined as 100 times the difference between estimated value for each field and country estimated value divided by country estimated value.

[24] Lloyd, S. M.; Ries, R. Characterizing, Propagating, and Analyzing Uncertainty in Life Cycle Assessment: A survey of Quantitative Approaches. *Journal of Industrial Ecology* ***2007****, 11, (1), 161-179*

P – Production, VFF – venting, flaring, and fugitive emissions, U –total upstream

Country				Major Crude-Oil				Company				Field				Deviation in Field vs. Country Estimates		
Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	P	VFF	U
Russia	2.91	5.58	8.49	ESPO								Tomsk Oblast and the Khanty-Mansi Autonomous Okrug Fields	3.87	6.51	10.38	33%	17%	22%
				Sokol								Multiple offshore fields (Chayvo, Odoptu, and Arkutun-Dagi)	1.90	6.59	8.48	-35%	18%	0%
				Vityaz								Multiple offshore fields: Piltun-Astokhskoye oil & the Lunskoye natural gas field)	3.83	4.63	8.46	32%	-17%	0%
				M100								Multiple onshore fields in Urals region. Assumed the Romashkino oil field	5.65	6.45	12.10	94%	16%	43%
Saudi Arabia	3.77	1.91	5.68	Arab Extra Light								Multiple fields	3.92	1.96	5.88	4%	2%	3%
				Arab Light								Vast majority in the Ghawar field	3.84	1.89	5.74	2%	-1%	1%
				Arab Medium								Multiple onshore and offshore fields	3.55	1.88	5.43	-6%	-2%	-4%
Nigeria	1.33	16.91	18.24	ABO				NAE					2.38	3.56	5.93	78%	-79%	-67%
				Agbami								Chevron 1	1.14	17.59	18.73	-15%	4%	3%
				Amenam								Total E&P 1	1.36	12.99	14.35	2%	-23%	-21%
				Antan	2.61	33.72	36.34	Addax	2.80	35.94		Addax 1	2.19	35.94	38.13	64%	113%	109 %
												Addax 2	3.41	35.94	39.35	156%	113%	116 %
								Other	1.30	17.96		Other 1	0.68	17.96	18.65	-49%	6%	2%
												Other 2	1.91	17.96	19.87	43%	6%	9%
				Bonga				SNEPCO					1.18	2.43	3.61	-11%	-86%	-80%
				Bonny Light	-0.36	14.75	14.39	SPDC					-0.85	14.70	13.85	-163%	-13%	-24%

Country				Major Crude-Oil				Company				Field				Deviation in Field vs. Country Estimates		
Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	P	VFF	U
								Chevron	1.75	17.59	19.34	Chevron 1	1.14	17.59	18.73	-15%	4%	3%
												Chevron 2	2.36	17.59	19.95	77%	4%	9%
								Total E&P	1.97	12.99	14.96	Total E&P 1	1.36	12.99	14.35	2%	-23%	-21%
												Total E&P 2	2.58	12.99	15.58	94%	-23%	-15%
								Other	1.30	17.96	19.26	Other 1	0.68	17.96	18.65	-49%	6%	2%
												Other 2	1.91	17.96	19.87	43%	6%	9%
				Nigeria-Brass	-0.45	73.01	72.56	SPDC					-0.85	14.70	13.85	-163%	-13%	-24%
								Chevron	1.75	17.59		Chevron 1	2.36	17.59	19.95	77%	4%	9%
												Chevron 2	2.36	17.59	19.95	77%	4%	9%
								NAOC Phillips					-1.25	89.11	87.85	-194%	427%	382%
								Addax	2.80	35.94		Addax 1	2.19	35.94	38.13	64%	113%	109%
												Addax 2	3.41	35.94	39.35	156%	113%	116%
								AENR					4.61	48.70	53.32	246%	188%	192%
								Other	1.30	17.96		Other 1	0.68	17.96	18.65	-49%	6%	2%
												Other 2	1.91	17.96	19.87	43%	6%	9%
				EA	SPDC EA			SPDC EA					0.85	1.18	2.03	-36%	-93%	-89%
				Erha	Esso Erha			Esso Erha					3.08	3.57	6.65	131%	-79%	-64%
				Escravos	2.35	17.59	19.94					Chevron 2	2.36	17.59	19.95	77%	4%	9%
								Other	1.30	17.96		Other 1	1.91	17.96	19.87	43%	6%	9%
												Other 2	0.68	17.96	18.65	-49%	6%	2%
				Forcados	-0.35	16.80	16.46	SPDC					-0.85	14.70	13.85	-163%	-13%	-24%
								NAOC Phillips					-1.25	89.11	87.85	-194%	427%	382%
								Pan Ocean					5.02	23.57	28.60	276%	39%	57%
								NPDC	1.24	24.02		NPDC 1	1.86	24.02	25.88	39%	42%	42%
												NPDC 2	0.63	24.02	24.65	-53%	42%	35%
								Other	1.30	17.96		Other 1	1.91	17.96	19.87	43%	6%	9%

Country				**Major Crude-Oil**				**Company**				**Field**				**Deviation in Field vs. Country Estimates**		
Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	Name	P	VFF	U	P	VFF	U
												Other 2	0.68	17.96	18.65	-49%	6%	2%
				Okono								NPDC 2	0.63	24.02	24.65	-53%	42%	35%
				OKWB								Addax 1	2.19	35.94	38.13	64%	113%	109%
				Pennington	1.46	20.44	21.90					Pennington	1.76	24.86	26.62	32%	47%	46%
								Other	1.30	17.96		Other 1	1.91	17.96	19.87	43%	6%	9%
												Other 2	0.68	17.96	18.65	-49%	6%	2%
				Nigeria-Qua Iboe								Mobil	2.78	10.89	13.66	108%	-36%	-25%
				Nigeria-Usan								Total E&P 1	1.36	12.99	14.35	2%	-23%	-21%
				Nigeria-Yoho								Mobil	2.78	10.89	13.66	108%	-36%	-25%

Appendix E: OPGEE MCONS Analysed

The table below includes the MCONS analysed the results for 95% flaring efficiency model runs.

Crude MCON	Crude Oil Production	VFF	Crude Oil Transport	Diluent	Non-Integrated Upgrading	Total Well to Refinery GHG Intensity	MCON Crude Coverage
Russia-ESPO	3.87	6.51	1.92	0.00	0.00	12.30	6%
Russia-Sokol	1.90	6.59	0.65	0.00	0.00	9.13	
Russia-Vityaz	1.41	4.63	0.81	2.41	0.00	9.27	
Russia Region-Mazut M100	5.65	6.45	2.50	0.00	0.00	14.61	
Libya-Amna	2.92	7.86	1.79	0.00	0.00	12.57	12%
Saudi Arabia - Arab Extra Light	3.92	1.96	1.57	0.00	0.00	7.45	51%
Saudi Arabia - Arab Light	3.84	1.89	1.58	0.00	0.00	7.32	
Saudi Arabia - Arab Medium	3.55	1.88	1.41	0.00	0.00	6.84	
Nigeria-ABO	2.38	3.56	1.62	0.00	0.00	7.55	100%
Nigeria-Agbami	1.14	17.59	1.62	0.00	0.00	20.34	
Nigeria-Amenam	1.36	12.99	1.62	0.00	0.00	15.97	
Nigeria-Antan	0.74	18.63	1.62	0.00	0.00	20.99	
	2.19	35.94	1.62	0.00	0.00	39.75	
	0.68	17.96	1.62	0.00	0.00	20.27	
Nigeria-Bonga	1.18	2.43	1.62	0.00	0.00	5.23	
Nigeria-Bonny Light	1.59	17.16	1.62	0.00	0.00	20.37	
	-0.85	14.70	1.62	0.00	0.00	15.47	
	2.36	17.59	1.62	0.00	0.00	21.57	
	2.58	12.99	1.62	0.00	0.00	17.20	
	1.91	17.96	1.62	0.00	0.00	21.49	
Nigeria-Brass	1.47	21.08	1.62	0.00	0.00	24.17	
	-0.85	14.70	1.62	0.00	0.00	15.47	
	2.36	17.59	1.62	0.00	0.00	21.57	
	-1.25	89.11	1.62	0.00	0.00	89.47	
	3.41	35.94	1.62	0.00	0.00	40.97	
	4.61	48.70	1.62	0.00	0.00	54.93	
	1.91	17.96	1.62	0.00	0.00	21.49	
Nigeria-EA	0.85	1.18	1.62	0.00	0.00	3.65	
Nigeria-Erha	3.08	3.57	1.62	0.00	0.00	8.27	
Nigeria-Escravos	2.36	17.59	1.62	0.00	0.00	21.57	
	1.91	17.96	1.62	0.00	0.00	21.49	

Crude MCON	Crude Oil Production	VFF	Crude Oil Transport	Diluent	Non-Integrated Upgrading	Total Well to Refinery GHG Intensity	MCON Crude Coverage
Nigeria-Forcados	1.31	21.07	1.62	0.00	0.00	24.00	100%
	-0.85	14.70	1.62	0.00	0.00	15.47	
	-1.25	89.11	1.62	0.00	0.00	89.47	
	5.02	23.57	1.62	0.00	0.00	30.21	
	1.86	24.02	1.62	0.00	0.00	27.50	
	1.91	17.96	1.62	0.00	0.00	21.49	
Nigeria-Okono	0.63	24.02	1.62	0.00	0.00	26.27	
Nigeria-OKWB	2.19	35.94	1.62	0.00	0.00	39.75	
Nigeria-Pennington	0.69	18.01	1.62	0.00	0.00	20.32	
	1.76	24.86	1.62	0.00	0.00	28.24	
	0.68	17.96	1.62	0.00	0.00	20.27	
Nigeria-Qua Iboe	2.78	10.89	1.62	0.00	0.00	15.28	
Nigeria-Usan	1.36	12.99	1.62	0.00	0.00	15.97	
Nigeria-Yoho	2.78	10.89	1.62	0.00	0.00	15.28	
Azerbaijan-Azeri	2.39	1.81	2.29	0.00	0.00	6.48	81%
Algeria-Saharan	2.46	6.01	1.65	0.00	0.00	10.13	18%
Angola-Cabinda	2.31	4.44	1.66	0.00	0.00	8.41	93%
Angola-Dalia	2.20	4.42	1.70	0.00	0.00	8.33	
Angola-Gimboa	2.05	4.40	1.70	0.00	0.00	8.14	
Angola-Girassol	2.38	4.68	0.89	0.00	0.00	7.95	
Angola-Greater	2.09	4.46	1.68	0.00	0.00	8.23	
Angola-Hungo	1.78	4.08	1.69	0.00	0.00	7.56	
Angola-Kissanje	2.06	4.40	1.68	0.00	0.00	8.14	
Angola-Mondo	2.06	4.50	1.69	0.00	0.00	8.25	
Angola-Nemba	2.32	4.59	1.64	0.00	0.00	8.55	
Angola-Pazflor	1.65	4.03	1.70	0.00	0.00	7.38	
Ecuador-Napo	3.83	3.83	0.52	0.00	0.00	8.18	100%
Ecuador-Oriente	4.62	4.44	0.52	0.00	0.00	9.58	
Equatorial Guinea-Ceiba	1.84	5.97	1.61	0.00	0.00	9.41	6%
Brazil-Albacora Leste	1.48	2.15	1.42	0.00	0.00	5.05	96%
Brazil-Bijupira	2.75	2.25	1.39	0.00	0.00	6.39	
Brazil-Frade	1.20	2.02	1.42	0.00	0.00	4.64	
Brazil-Jubarte	3.60	1.69	1.41	0.00	0.00	6.70	
Brazil-Lula (Tupi)	4.98	1.74	1.39	0.00	0.00	8.11	
Brazil-Marlim	3.02	1.66	1.42	0.00	0.00	6.11	
Brazil-Marlim Sul	2.91	2.49	1.40	0.00	0.00	6.81	

Crude MCON	Crude Oil Production	VFF	Crude Oil Transport	Diluent	Non-Integrated Upgrading	Total Well to Refinery GHG Intensity	MCON Crude Coverage
Brazil-Polvo	1.80	1.67	1.42	0.00	0.00	4.88	96%
Brazil-Roncador(Snorer)	1.71	2.66	1.39	0.00	0.00	5.76	
Brazil-Roncador Heavy	2.32	1.72	1.42	0.00	0.00	5.46	
Brazil-Sapinhoa	3.70	1.71	1.39	0.00	0.00	6.81	
Venezuela-Boscan	5.89	2.39	0.76	0.00	0.00	9.03	22%
Venezuela-Hamaca	2.20	2.34	0.85	0.00	16.87	22.26	
Venezuela-Hamaca DCO	1.87	1.99	0.85	1.21	0.00	5.92	
Venezuela-Mesa 30	5.40	3.47	0.82	0.00	0.00	9.69	
Venezuela-Petrozuata	2.22	2.34	0.85	0.00	16.87	22.29	
Venezuela-Zuata Sweet	2.20	2.34	0.85	0.00	16.87	22.26	
Kuwait-Kuwait	5.23	2.14	1.45	0.00	0.00	8.82	100%
Congo-Azurite	1.59	6.86	1.67	0.00	0.00	10.12	20%
Congo-Djeno	1.86	6.93	1.67	0.00	0.00	10.46	
Cameroon-Lokele	1.76	18.06	1.64	0.00	0.00	21.46	50%
UAE(Abu Dhabi)-Murban	4.81	1.96	1.48	0.00	0.00	8.25	77%
UAE(Abu Dhabi)-Upper Zakum	3.97	1.90	1.40	0.00	0.00	7.26	
Argentina-Canadon Seco	3.99	1.89	1.80	0.00	0.00	7.68	100%
Argentina-Escalante	4.00	1.90	1.80	0.00	0.00	7.70	
Argentina-Hydra	2.55	2.19	1.78	0.00	0.00	6.52	
Argentina-Medanito	4.09	2.26	1.88	0.00	0.00	8.23	
Oman-Oman	11.79	3.27	1.50	0.00	0.00	16.56	100%
Conventional	2.40	3.82	1.47	0.00	0.00	7.70	
Steam Flood	21.17	2.71	1.53	0.00	0.00	25.42	
Iraq-Basra Light	4.10	6.02	1.48	0.00	0.00	11.60	87%
Mexico-Isthmus	5.85	2.50	0.27	0.00	0.00	8.61	83%
Mexico-Maya	4.11	2.10	0.85	0.00	0.00	7.05	
Chad - Doba	2.97	1.66	1.95	0.00	0.00	6.58	26%

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