Reducing the Carbon Footprint of Drilling and Completion Operations

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Abstract

The use of planning tools to minimize waste and discharges to the environment during well construction is fast becoming the norm in the oil and gas industry. Air emission control through the same approach is also desirable. Calculating the carbon footprint of a well construction operation is however usually done after the event. When planning the well, air emissions are generally taken into account through qualitative evaluations, and consideration of emissions from disposal activities appears to be somewhat rare. Nevertheless there is a clear advantage in a quantitative analysis of the operation, as it supports emission mitigation at source and allows the engineer to compare different operational choices.

The objective of the development work undertaken was to create a user-friendly yet scientifically defensible methodology for calculation of greenhouse gas (GHG) emissions, air pollutants, fuel consumption and fuel costs before well construction takes place. The aim was to enable engineers to compare different operational choices in a quantitative manner. The developed methodology utilises databases of equipment, specific energy consumption and specific emission factors and allows pre-operational calculations without the need for detailed data on actual power consumption or fuel use. This allows targeted emission mitigation to be incorporated into the planning stage.

The initial phase of the project included a review of GHG calculation methodologies and the air emission reporting requirements in the EU and the USA. Existing methodologies appear to have been designed to support post-operational calculations, where accurate data on fuel consumption and fuel consistency is known, thus some methodology development was required as such data is not available before an operation.

The approach used in this calculator takes into account all aspects of the operation that can be influenced by the operator: Logistics, equipment, fluid choices and waste management options, including different end disposal options. The results include both detailed breakdowns and rapid overviews of emission sources both for greenhouse gases and the traditional air pollutants. Applying the concepts developed in the planning stage supports identification of best practices and allows targeted improvement efforts towards areas of greater emissions. The actual tool can be used for both comparisons during the design stage and as an aid to audits for accurate post-operational emissions audits.

Introduction

Oil and gas is produced through wells drilled into hydrocarbon-bearing rock formations, often deep underground and sometimes sited in challenging offshore environments. The overall operation is highly complex and minimisation of potential environmental impacts is an important goal of the planning stage. Discharges and waste impacts are often modelled in detail as part of an environmental impact assessment procedure. These assessments are generally thorough, incorporate all environmental aspects and are conducted by experts. The earlier in the planning stage that environmental aspects are considered, the more integrated environmental considerations become.

There are several planning tools and methodologies for assessing waste and discharge impacts. Quantitative assessments on relative energy use and emissions are in general somewhat laborious to construct and require detailed data. Frequently the focus of emission assessments is on flaring and how to avoid/control this. Accurate pre-operational assessments of overall operational air emissions or energy use are less commonly supported. Whilst the most accurate results are gained from detailed expert assessments, engineers need tools that allow rapid estimation of predicted environmental impacts of the waste, emissions and discharges related to the operation.

Assessing the emissions and energy use of different operational alternatives at the design stage would support more informed decisions and help to ensure the greenhouse gas potential of an operation may be taken into account. However, there are both practical and theoretical challenges associated with this, including:

1. Most air emission calculation methodologies are designed to use data on <u>actual</u> used energy and fuel. The **theoretical challenge** is how to ensure consistency of results when neither accurate fuel consumption data nor established emission factors are available for the planned operations. This is particularly true for transport assessments, where for example, established emission factors do not readily fit the typical offshore vessel classes used to support offshore drilling operations.
2. Engineers and managers need a rapid and reliable way of reasonably estimating the emissions associated with different operational and logistic choices. The **practical challenge** faced in this project was related to minimising the need for engineers to provide data input related to energy use.

As current methodologies and tools do not meet both of these challenges at the same time the need to develop a suitable methodology and supporting tool was identified.

The overall objective of the work was to design a method for quantitative estimation of the air emissions that does not rely on measured energy consumption. The method must produce comparable results across the globe and be presented as a practical tool that is suitable for operational engineers without environmental assessment expertise. The approach taken was to embed all calculations in a software tool. The input required is solely related to operational design. This allows engineers to routinely run air emission estimates for different operational concepts during the planning stage or when comparing bids by suppliers.

By necessity the approach contains some assumptions in order to utilize easily available data on equipment and material requirements. This approach is not intended to be used instead of expert assessment during the environmental impact assessment, although the results can be incorporated in to such assessments. The tool can also be run again after an operation with real term data to assess how accurate the initial assessment was. The developed methodology and supporting tool allows the calculation of the estimated carbon footprint of an operation, including transport, operational equipment, waste management options and emissions from final disposal.

This paper first presents the assumptions made to define the methodology and secondly provides an overview of the tool itself. Finally, a discussion on benefits and drawbacks of the approach is given.

Objective and Methodology

The aim of the project was to develop a scientifically defensible methodology that supports quantitative assessment of greenhouse gas emissions, air pollutant emissions, fuel consumption and fuel costs before an operation is carried out. Certain boundaries were set for the work in order to focus on the areas where the operator can influence the emissions through project design and supplier choices. An overview of the system boundaries applied to the work is given in Figure 1.

The operations included in the assessment covers all operations related to drilling and completion operations carried out on the rig as well as the treatment and end disposal of the waste created,. Manufacturing or fluid treatment done by the fluid suppliers as part of fluid recovery has not been included, as this process is outside the influence of the operator. Cementing was not included in the work scope. Neither were the overall rig emissions or the logistics of transferring equipment to the rig, as it was considered these choices were largely outside the influence of the operator. These exclusions can be amended once the overall concept becomes a familiar tool and proves useful in actual decision making.

The logistics considered included all logistic operations on the rig. The start point of the logistic chain was the loading of the required fluids and potential skips onto land transport to either the rig or to the port. Rail transport was not included at this stage.

The work included a literature review of GHG calculation methodologies and the air emission reporting requirements in the EU and the USA. All existing methodologies appear to have been designed to support post-operational calculations, where accurate data on fuel consumption and fuel consistency is known. In order to allow pre-operational comparisons of options, some modification to existing methodologies were made. The objective of the methodology selection and adaptation was to facilitate the creation of a practical tool for advance consideration of comparative emissions for planned drilling and completion operations, prior to any actual physical work being undertaken onsite.

The methodology was implemented in an Excel-based software tool to ensure ease of use and ready access within the company. The main aim of the development work was to create a practical tool that:

1. Supports quantitative assessment of operational alternatives
2. Can be run before or after operations, allowing both estimates and audit type use
3. Supports reporting requirements, such as existing reporting requirements on air emissions
4. Provides material suitable to include in decision making analysis (target group management)
5. Comprehensively covers the part of the lifecycle of a well construction fluid that the operator can influence
6. Requires minimal user input

The tool includes several databases. Emission factors and the energy consumption of operational and logistic equipment were included in these. The tool development proceeded through several rounds of testing and modification. The calculated results include energy use, air emissions and cost of energy.

Adopting Existing Methodologies to Pre-operational Assessments

There are currently several approaches to counting greenhouse gas (GHG) emissions for energy production. This includes various approaches applicable to oil/gas drilling rigs (IPIECA 2003, API 2004). In general, the methodologies have been constructed to count occurred emissions. All methodologies encompass two main parts:

1. Establishing the energy consumption
2. Arriving at the emissions through application of emission factors

In order to utilise current methodologies to support pre-operational quantitative analysis, certain adaptations had to be made. These relate to the required accuracy of results, the degree of carbon oxidation, fuels and emissions included, fuel specific emission factors, energy efficiency, source of emission factors for grid electricity and indirect emissions and which purchased energy emission factors to use. Emission factors used for the logistic chain were not adequate and therefore had to be developed. The methodology for these and the assumptions for end disposal emission calculations are described later on in the paper.

The Degree of Accuracy Required of the Results

The main aim of the developed methodology is to allow operational personnel to quantitatively consider relative greenhouse gas and air pollutant emissions of different waste management and well construction fluid choices during the planning stage. When the planned operation takes place, it is considered highly likely that it will deviate from the planned one at least to some degree. Due to this degree of uncertainty, absolute accuracy in the calculation methodology is therefore not seen as the key factor; instead the ability to compare operational approaches in a consistent way across the globe is paramount.

During the methodology selection, the emphasis has therefore been on ensuring comparability between alternative operational solutions whilst minimizing manual data input and maximizing user friendliness of the resulting tool. Therefore, whilst the methodology supports full comparability of alternatives at the planning stage, a variance between pre-operationally estimated emissions and post-operationally calculated emissions is to be expected. At the same time, the post-operational measured data will provide an evaluation point against which to validate the degree of accuracy of the pre-operational input data.

Degree of Carbon Oxidation

Carbon dioxide (CO_2) conversion fractions are in general high (99 – 99.5 % for petroleum fuels and natural gas[1]) and very similar for different fuels. Where possible, fuel specific conversion rates have been added. However, it has not been possible to source all greenhouse gas emission factors from public sources for the transport of materials. Where fuel specific conversion rates are not available, it has therefore been assumed that 100 % of the fuel's carbon content is converted into (CO_2). However, the tool contains the potential to add these conversion factors in the future.

Fuels and Emissions Included:

Fuels included were diesel, kerosene, LPG, natural gas and fuel oil. The emission factors were preferentially sourced from the GHG protocol. The greenhouse gas emissions are calculated for CO_2, CH_4 and N_2O. The greenhouse gases HFCs, PFCs and SF_6 were not included in the tool, since these greenhouse gases are not generated or released in typical drilling or completion operations. The decision was taken to include air pollutant emissions as well as greenhouse gases in order to paint a more complete picture of overall emissions. For these emissions, the Environmental Emissions Management System (EEMS[2]) approach by the UK regulator was taken as guidance. The considered emissions include NOx, SO_2, CO and VOC.

Source of Fuel Specific Emission Factors:

Once the energy consumption has been established for a particular piece of equipment for a specific running time, the result can be multiplied by the chosen, fuel specific emission factors to establish the emissions. The most accurate calculations are accomplished if each fuel specific emission factor is based on actual fuel composition, i.e. on the true carbon content of the specific fuels used for that particular operation. However, as this more or less requires regular chemical composition analysis of the fuel(s) used, it renders the approach both cumbersome to use in audits and wholly unsuitable to estimate emissions in advance. This approach was therefore discarded. Instead, the most widely utilized approach, i.e. applying published, fuel specific (average) emission factors to calculate the emissions was taken.

Published emission factors can in general be considered to represent a fairly accurate prediction of actual emissions. The differences in emission factors between different fuels are also much larger than differences between the emission factors of the same fuel from different regions and/or refineries. For example the composition of natural gas varies considerably according to location and location specific emission factors should ideally be included in future development work. However, for the purpose of comparative, in-advance calculations, inclusion of the highest possible accuracy in fuel specific emission factors is neither considered particularly relevant nor practical.

In the tool, emission factors have been sourced from several instances: The IPCC (IPPC 2006), GHG Protocol tools (WRI/WBCSD, 2004), DEFRA (DEFRA 2008) EEMS (EEMS 2009) and VTT Lipasto (VTT 2008). The guiding choice was to preferentially use emission factors from the GHG Protocol, but where these were not available, other sources were used. The used emission factors per fuel type are given in Table 1.

Where reliable sources were not available, the conservative assumption was made to consider all emissions as uncontrolled. As far as sulphur emissions are concerned, diesel oil sulphur content is assumed to be 2.7 %. For kerosene, jet kerosene emission factors for NOX, (SO2), CO and VOC are applied since IPCC does not contain these emission factors for 'other kerosene'. The LPG emission factors used are those of 'US light- and heavy-duty LPG vehicles (passenger cars)' (IPPC 2006). For fuel oil, the diesel emission factors were used, as the actual emissions will depend on the precise composition of fuel oil, which depends upon the variety (e.g. fuel oil #1, #2, etc). Whilst these approximations are not ideal, the decision was made to use available emission factors rather than develop specific ones for these marginally used fuels. It should be noted that once more accurate data can be established, the emission factor values can be readily adjusted in the tool.

Energy Purchases and Indirect Emissions

National and regional emission factors for purchased energy (electricity) are compiled to reflect the site-dependent mix of commercial energy production types. The indirect emissions from purchased energy (electricity) are calculated in published national or location specific (state or province) emission factors. The use of location specific emission factors for purchased energy is important, as the different waste processing or equipment alternatives may be most favourable in different locations. To illustrate, if an on-shore rig is grid-connected, and the local grid-electricity has low emission factors, the overall emission calculations may favour other process solutions on the rig, than at another, otherwise similar site where the local emission factors for grid-electricity are high. Thus it is argued that it is important that the location specific emission factors are incorporated as part of the tool.

For pragmatic reasons, published national/state level data has been assumed accurate enough: comparative data is available for a large number of countries and these have been incorporated into a calculation tool. The two approaches to emission factor compilation that are most widely recognized are the Greenhouse Gas Protocol (GHG Protocol) established by the World Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD) and the API protocol established by the American Petroleum Institute. However, neither the GHG nor the API protocol includes other emissions than greenhouse gases. Therefore, the decision was taken not to calculate these for grid electricity. However, for the sake of consistency, these should be included during further development.

A potential for inaccuracy related to using purchased energy emission factors arises due to the fact that these bodies have calculated the emission factors differently:

- The Greenhouse Gas Protocol combines all energy forms and all fuels to come up with a single emission factor for purchased energy, whether it be electricity, combined heat and power (CHP), or heat-only.
- API calculates country specific emission factors for grid electricity based on emission factors for generation technologies (supplied by the USA Department of Energy) and country specific electricity generation statistics. In these calculations, CHP production is obviously not taken into account, instead, all emissions are allocated to electricity. This is probably quite accurate in countries where electricity is produced by condensing power but not necessarily in areas with a lot of CHP production.

Thus, neither of these two protocols is ideal for situations where only electricity is purchased from the grid. Due to the differences in utilized primary energy sources between different countries and regions, it is however considered appropriate to take the location specific energy mix into account for estimating indirect emissions from purchased energy. Therefore, both protocols are incorporated into the tool and the user can choose whether to use API or GHG in the US and Canada. Elsewhere, the wider scoped GHG Protocol location specific emission factors for purchased energy are used. The arithmetic average of the CO_2 emission factors of the three most recent tabulated years is applied, in order to even out annual fluctuations.

Calculating the Energy Use on the Rig

Rig emissions included were limited to drilling and completion specific equipment. Overall emissions from rig are not included at this stage. Equipment emissions are calculated by multiplying the estimated fuel/electricity consumption (per equipment) with the relevant fuel specific emission factor or country (and region) specific grid electricity emission factor.

To establish the energy consumption, the most obvious and robust way is to measure the actual fuel consumption per specific type of energy source /fuel and per operation. Using measured consumption is both practical and accurate for post-operational inventory calculations. However, quantitative assessments done prior to an operation being carried out cannot rely on actual energy consumption, as any particulars for a future operation cannot be known exactly. Neither can the user be expected to directly predict energy consumption. Energy consumption therefore had to be arrived at based on available data and user input of only such variables that can be reasonably accurately predicted by the user. The quality and scope of the data included in the databases and the required input data by the user therefore required careful balancing between practicality and accuracy.

The decision was made to base calculations on equipment specific energy consumption and running times. Running time is estimated by the user. Data on specific equipment was collated into several databases, based on data supplied by manufactures or sourced from public sources. The values given by manufacturers may not always be established in comparable manners. Where no accurate estimate on energy consumption for relevant equipment was found, the energy consumption was estimated. Inevitably, these assumptions bring uncertainty to the results. However, the data can be readily edited whenever more accurate estimates are available. It is recommended that where post-operational accurate calculations

are carried out; the data is used to refine the energy consumption data included in the tool. Over time, the approach would in this way become increasingly accurate.

The following areas required some methodology development: Energy estimates in relation to energy sources; estimates of energy efficiency of equipment; and a combined and simplified fuel and technology based approach. These are described in the following sections.

Energy Sources:

There are several possible sources of energy available on a rig. All have been included in the tool, where the user is given a choice for each equipment power supply: grid electricity, rig generators, combined grid and general rig generator(s), – in this case the user has to give an estimate of the grid power share of the total energy consumption on the rig – equipment powered by equipment specific generators and equipment run by its own fuel, naming the fuel. Whilst grid electricity and fuel powered equipment are relatively straightforward to assess, generators require a more complex approach to take into account generator efficiency and other variables.

Generally, there is no way of knowing, which generators are used for which purpose (unless detailed electrical plans of the rig are available and they indicate direct and exclusive 'paths' of generated electricity) and whether they are running at partial or full load at any arbitrarily chosen moment. In an ideal situation, generator part-load efficiencies through data from the generator manufacturers and typical running profiles, such as how many hours at each power level, or durability curves (through historical data from various operations and various circumstances) would be available. Then quite accurate average generator efficiency values could be calculated in-advance. The average efficiency calculation would be based on part-load efficiency data from the generator manufacturers and a case-fitting durability curve. This type of data was however not available. Thus, a simplified model had to be adopted. The following assumptions were made:

Firstly, only the nominal power operation of generators is considered. This also applies to the efficiency (fuel to electricity). A separate generator efficiency degradation factor can easily be added to the calculations at a later stage, should one be developed. In the current version, all efficiency degradation – both that of generators and that of equipment – is aggregated into a single default or user given factor.

Secondly, generators were divided into two groups: general rig generators (all-purpose generators) and equipment-specific generators (or exclusive generators, used only within the chosen system boundaries, typically to power a single piece of equipment). The user chooses the energy source for each piece of equipment. The choice of energy source has an effect on the energy consumption and emissions calculations. Nominal power and fuel consumption at nominal power is listed for all generators in the database, and the generator-specific efficiency is obtained either from the manufacturer data or by dividing the nominal power by the fuel consumption (in power units) at nominal power.

Thirdly, general rig generators (all-purpose generators) chosen by the user are summed and a nominal power weighted average of their efficiencies is used to calculate their fuel consumption and emissions. In effect, this means that the peak power time of all chosen general rig generators is assumed to be the same. This is, admittedly, a simplistic approach, but in order to keep the tool easy to use, the user is not asked to estimate the peak power times of the chosen generators. Echoing this decision, average fuel energy densities and average fuel-specific emission factors are also used in the case of more than one fuel being used by the generators. These averages are also generator nominal power weighted.

Fourthly, in order to facilitate as easy use of the tool as possible, the user is given the possibility to choose non-specific generators for general rig generators, named simply 'small', 'medium' and 'large', along with the fuel used by each of the chosen ones. These three 'generators' represent the average of database generators in three power bands, 0 – 100 kW (electric), 100 – 1000 kW and more than 1000 kW, respectively. Each of these representatives is given the average efficiency value from the relevant real generator efficiencies within that power band in the generator database. So, whenever the user chooses a non-specific generator, its efficiency is determined by the size class and the emissions by the selected fuel.

Lower than Specified Efficiency of all Fuel Consuming Equipment

The age and the condition of a generator, or any other fuel consuming device, can have a more significant effect on the efficiency than the fuel type. Lowered efficiency may result from several reasons, e.g. increased friction due to wear and tear (mechanical), incomplete carbon oxidation (chemical), increased electrical losses, etc. As it is quite difficult to establish accurate efficiency values - especially before operations - the decision was made to combine all possible efficiency loss factors into one factor, which is used to multiply manufacturer efficiency values in all instances. The variation of this efficiency loss factor per equipment type and per individual equipment may be of considerable difficulty to estimate in advance of operation.

Three potential options for the methodology were identified:
1. The wear and tear of equipment is taken into account through user input (as an efficiency percentage)
2. The wear and tear is taken into account for all equipment on the same level, providing an estimated average effect over a number of operations
3. The wear and tear factor is not taken into account at all and optimum conversion is assumed.

Based on practical considerations, the decision was made to set the generic efficiency factor for all equipment at 95%, i.e. a 5% loss of efficiency due to various factors. Where better data was available from the field, the efficiency factor was adjusted.

However, once post-operational data is available for a certain type of equipment, this factor can be adjusted to achieve a better pre/post match. The user is also given the possibility to provide more accurate values for each piece of equipment. For example, if the user knows the general equipment may be of relatively old stock, the efficiency factor should be adjusted down.

Rig Equipment Energy Consumption

In order to construct a practical yet reasonably accurate predictive emission calculation model, a combined fuel and technology based model was constructed based on estimating running time at two power levels and using this to calculate estimated fuel/electricity consumption and consequent emissions.

The fuel/electricity consumption data from manufacturers are entered into the database. The basic assumption behind the methodology is that both peak power and idle time consumption is available. This data is used to calculate total fuel/electricity consumption. This is adopted where data is available. Where idling time consumption is either not available for specific equipment, the most conservative assumption has been made, that is: idling time consumption is the same as peak power consumption[1]. This reflects the worst case data from manufactures on certain equipment, e.g. shakers. The user of the tool can, of course, replace the default by more accurate, case-specific data.

This approach requires the following two inputs by the user:
1. How many hours a piece of equipment will be running (total hours, including full power and idling hours).
2. Expected idling time as a percentage of the total time the equipment is used

These user estimations are expected to be based on practical experience. Idling time default values have been provided for each type of equipment based on data from field users. Where more accurate estimates are available, the user can override the default values.

Calculating the Energy Use and Emissions from Logistics

The logistical steps covered include road transport, loading/unloading and shipping. Loading and unloading is assessed on a time used basis, as the time to carry out these functions is more relevant and more easily assessed than the distance covered. The calculations of energy use and emissions for the loading equipment are therefore based on the same methodology as the rig use presented in the previous section. Tonnage to be loaded is shown to aid the user in estimating the loading time required per equipment type.

During the development, the decision was taken to calculate emissions from the transport steps within the logistics chain in relation to transported material weight and distance transported. Here, the GHG protocol and the IPCC proved inadequate. The UK Department for Environment, Food and Rural Affairs (DEFRA) classification and emission factors per tonne-kilometre for light and heavy goods vehicles (DEFRA 2008) were found to be applicable to the approach and used with minor modifications. This ensures that the appropriate proportion of transport consumption can be allocated to the project. For shipping, there appeared not to be any such standardised emission factors that can be applied to the types of vessels typically used to support offshore drilling operations so these were developed during the project from average fuel consumption under load of typical offshore vessels.

Shipping Emissions and Energy Consumption

Assessment of the shipping emissions required a unique approach since directly suitable emission factors for typical offshore vessels were not available. Thus, the following methodology was developed:
1. The type of vessels used for offshore supply were broadly categorised into two types: Offshore supply vessels and anchor handling vessels. Both ship types where divided into two size classes, below and above 2500 DWT (Dead Weight Tonnage). This was considered adequate as the user is unlikely to know in advance exactly what type of vessel will be available.
2. Fuel consumption and service speed data of real vessels were collected and tabulated into a shipping database, according to the defined size classes.
3. An average ship size per category was determined by calculating the average DWT, average service speed and average fuel consumption at service speed and at stand by at sea (tonnes/day).
4. A net cargo/DWT (mass-%) factor was added to the shipping database in order to facilitate the calculation of emission factors per cargo tonnage and distance – the initial value (40 % for all categories) of this factor was taken from VTT Lipasto (VTT 2008) but it should be reviewed and adjusted as more accurate data becomes available.
5. Based on the above ship database data and user input (ship category, distance and estimated stand by time at sea) the emission factors per cargo tonnage and distance are calculated. Service speed fuel consumption and stand by (at sea) fuel consumption are taken into account. Note that fuel consumption in port, which is generally part of a shipping tonnage/distance emission factor, was excluded. This can, if required, be added at a later stage.

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[1] This is a safe assumption and certainly does not underestimate idle time energy consumption, Furthermore; according to some manufacturer data, for example some main shakers consume the same amount of electricity both at peak load and when idle.

6. Ship fuel is assumed to be either diesel or fuel oil – an additional user input is needed if fuel choices are to be allowed in the future.
7. The approach assumes that the loading factor is 100 %, i.e. that any vessel will be sailing fully loaded both to and from an offshore rig. An additional loading factor can easily included if required in the future.

The ship type specific CO_2 emission factor per cargo tonnage and distance is calculated separately for each case, using Equation 1. The ship CO_2 emissions are then obtained by Equation 2 and the Ship energy consumption related to the net cargo transported is calculated backwards from the CO_2 emissions (Equation 3).

Road Transport Emissions and Fuel Use

In addition to the straight forward calculation – kilometres times cargo tonnes times emission factor – idling time fuel consumption and emissions are accounted for separately. The user gives an estimate of assumed idling time (motor running while not driving anywhere). The idling fuel consumption (litres/h) has been included in the road database. The value of idling time fuel consumption of the heaviest HGV's is based on information from US EPA Smartway. Values in the other weight classes are more tentative estimates for the time being, but they can be easily updated when more accurate data becomes available. CH_4 and N_2O emissions are not calculated for the time being, as specific emission factors per tonne-kilometre do not exist. However, the necessary calculations are included in the tool, and once emission factors can be established, these should be included.

Loading Equipment Energy Consumption and Emissions

The logistics include several stages of loading and unloading, onto trucks, ships and to/from the rig. The calculations are based on the tonnage of materials and cuttings boxes required. The user chooses the type of loading equipment from a specified list for each type of material. For each, the user then enters the expected time the equipment will be used and estimates the idling time. Default values for each type of equipment idling time have been included. The emissions and power use is then estimated using Equation 4, as exemplified for electric driven equipment:

If a loading equipment is directly connected to grid or to a generator (without battery), the Battery Cycle Efficiency factor is not applied. In the case of loading equipment batteries being charged with the rig generators, the energy (=fuel) consumption is obtained by dividing the Loading Electricity Consumption by the Average Rig Generator Efficiency, calculated as described earlier.

Waste End Disposal Emissions

Emissions from waste end disposal vary according to the end disposal method in how much of the carbon in the waste is converted to CO_2 and how much to CH_4. N_2O was not included, as the proportion is fairly low and the assumptions made fairly broad. The carbon present in the waste was calculated based on the different types of fluids used and initial proportion of carbon present in the fluid and additives. These are given in Table 2 and can be adjusted by the user within the tool.

The conversion proportions were estimated based on how readily available oxygen is for the waste decomposition in each end disposal type. The proportions assumed are presented in Table 3. At the time of development, it was decided not to attempt precision, as the mix of end emission gases are determined by various locational factors such as soil permeability, end disposal depth, water depth and soli type and microbial fauna within soil.

Note that these values can be modified by the user, should more accurate data be available. For example, the landfill emissions vary according to exactly how deep the material is filled in, and for material sited quite deep in a landfill, the methane proportion may easily be 50%.

Implementing the Methodology in a Practical Tool

Data Input Requirements

During the development process, emphasis was placed on requiring as little input from the user as possible. Apart from providing basic details on the well, the site and on power usage, the main input is on the defining the required inventory in detail as well as providing input to the waste volume calculator. Elsewhere, the user is mainly required to choose equipment from pick lists. For road and ship transport, the user needs to know the distance transported and estimate idling time in hours. For all other equipment, the user is asked for the use time. Idling time is provided as a default, this can be overwritten.

The minimisation of the user input gives the tool the added benefit of being fast, easy to use and very simple to learn how to use. This was achieved through careful design and some additional background calculations.

Tool Structure

The structure of the tool has been set to follow the boundaries of the assessed system (see Figure 1). In order to ensure the user can work in a logical fashion through each process, whether on the rig or off the rig, the following seven main work steps were used as a basis for the input design:

1. Set Up (specifications, units and well data)
2. Power generation (including emission protocol choice)
3. Inventory (materials required)
4. Waste management plan (treatments on and off rig and end disposal)
5. Logistics (fluids and waste)
6. Rig processes and equipment inputs
7. Reporting (Summary and detailed break downs)

Starting with the definitions in the set up section, the user then specifies the required materials and cuttings boxes and the waste management options of the operation (treatments and end disposal options). The power generation section contains details of where the energy is coming from, including generators. After this, the logistics steps are defined and specified. Finally, the actual equipment used for the operation is given in the rig system section. Each of these is described in the following section.

Set up and Inventory

The Set Up page is used to specify the operation. Units and well specifics are given here. An estimate of the Material Inventory is then given in the inventory sheet. The requirements are estimated per well section. Materials are specified as drilling /completion fluid, drill water, barite, bentonite, other bulk chemicals, sack and drum chemicals and cuttings boxes.

Power Generation

This section contains details on how the power is generated. It details the location, gives the option to choose the emission calculation protocol and whether the rig operations use grid power (applicable to onshore operations). Rig generators are specified either according to estimated size or as specific generator types, using dropdown menus. No numeric entries are required.

Waste Management

The amount of waste is first calculated per section in the waste volume page. The input required is the solids control efficiency % and the maximum allowable percentage of low gravity solids (LGS) % and the mud: solids ratio. If the waste drilling fluid is dewatered, this is specified via a check box as this will alter the final volume of waste for transportation and disposal. Then the waste treatment (on and off rig), skip size (if required) and end disposal is specified for both liquid and solid wastes, per well section. The specification is done through dropdown menus. This page also gives a summary of end disposal emissions. No numeric values are required from the user. The waste treatment equipment is specified in the waste treatment onsite and waste treatment offsite pages (see Rig operations for input requirements)

Logistics

The logistic steps included are given in Figure 2. The tool gives the user the potential to choose only those logistic steps that he /she will want to include in the assessment

Loading and unloading as well as lifts on rig are given through first selecting the equipment, then estimating the time it will be used, including any idling time as a percentage of total time. For road and ship transport, the distance transported is required and any idling time is estimated in hours. For all logistic steps, the equipment is chosen for each type of material transported.

Rig Operations

The rig operations are first defined and an overview of all operational steps is provided in a diagram format (see Figure 1) The rig operations are specified in 5 pages, namely: the circulating system, solids control, waste transfer (on rig) and waste treatment on rig. All of these pages have the same structure. Each has been broken down in operational steps for easier overview. For example, the circulating system page contains sections for mixing, pumping and degassing. First, the equipment used is chosen (type, manufacturer and make). Then the number of units and time used is specified. An example of the circulating system is given in Figure 3.

Reporting

The tool allows the user to define how results are reported. There is a standard summary report that is designed to give a rapid overview of all emissions, energy use and cost. This is pictured in Figure 4.

The reporting section also contains a more detailed standard report customization page that allows the user to define how the results are presented in a more detailed way from the following options:

- Summary of greenhouse gas emissions of all activities, break down per operational step
- Rig air emissions summary (includes air pollutants) per operational step on the rig.
- Energy use per operational step
- Energy costs per type of energy per operational step
- Waste stream summary (energy use, cost and emissions from waste handling and disposal)
- Transport summary (energy use, cost and emissions from transport)

Different types of reports, which vary in how detailed the breakdown of the emissions, costs and energy use can also be chosen. The results from the tool can easily be updated if more accurate estimates are forthcoming during the planning process.

Updating the Tool
The tool has been designed to allow easy updating. For example, all emission factors and other waste disposal emission breakdowns are tabulated and can be updated with relatively little work.

Benefits and Challenges of the Approach
There are several practical benefits to be had from using the methodology. Firstly, it allows consideration of air emissions and energy use and cost to be taken into account early on in the well planning stage. Secondly, by implementing the methodology in a tool, the assessment is accessible to engineers without the requirement for expert assessment. Whilst the tool should never be used as a substitute of expert EIA assessments, the results from the tool can be utilised as part of an EIA assessment. The main benefit in using this approach is that rapid comparative analysis of different waste management options or different equipments can be made. The methodology gives an overview of which processes are most energy consuming and where most emissions are created. This allows targeted mitigation strategies to be developed for each operation at an early stage in the planning cycle. By creating a picture of the overall emission and energy related consequences, the user can swiftly find areas that may require further consideration.
The challenges mostly relate to the scientific accuracy of the adopted methodology. During the development work, it was decided that absolute accuracy was less important to user friendliness. Whilst this decision was taken, the flaw was recognised and the tool constructed in such a way as to allow easy updates of both key parameters and equipment specific data. Nevertheless, it is acknowledged that environmental accounting (EMA) is a discipline striving for maximum accuracy. Therefore the option for the user to override estimates is given in the tool. This approach is considered to achieve sufficient ease of use for planning stages – and use by non-experts – whilst still giving the environmental expert a tool suitable for detailed analysis.

Conclusions and Recommendations
The developed methodology and accompanying tool represents a considerable step forward as it allows including emission considerations in the well construction planning stages in a rapid and accessible manner without previous knowledge of emission calculations. The tool itself requires very little numeric input and overall minimises user input requirement. No previous experience of quantitative emission analysis is required to use it. In this way integration of air emissions, energy use and energy costs into the planning stage can be achieved with limited time and resource allocation. The results include a management orientated summary report, which conveys the main results in a rapid overview mode. At the same time, the option for a more detailed expert analysis is contained. It is recommended that the results from predicted assessments should be analysed against actual results from post operational analysis. This will allow the methodology to be refined where necessary but most importantly, provide real data against which to check default values as well as compiling user guidance on "what to consider" when estimating usage times.

Acknowledgements

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Equations

Equation 1: Ship CO_2 Emission Factor [$kgCO_2$/tkm] = (Ship Fuel Consumption Sailing [kg of fuel] + Ship Fuel Consumption Standby [kg of fuel]) * Diesel CO_2 Content [$kgCO_2$/kg of fuel] /((ShipD istance [km] * DWT_[t] * ((Net Cargo/DWT)/100)))

Equation 2: Ship CO_2 Emissions [$kgCO_2$] = Ship Distance [km] * Ship Cargo Tonnage [metric tonnes] * Ship CO_2 Emission Factor [$kgCO_2$/tkm]

Equation 3: Ship Energy Consumption [kWh] = (Ship CO_2 Emissions [$kgCO_2$] / (Diesel CO_2 Content [$kgCO_2$/kg of fuel] / Diesel Density [kg/litre])) * Diesel Energy Density [kWh/litre]

Equation 4: Electric driven, electric energy – e.g. fork lift, crane, etc.: Loading Electricity Consumption[kWh] = (((1 – Loading Idling Time) x Loading Time Used) (h) x Electricity consumption on duty (kW) + (Loading Idling Time) x Loading Time Used(h) x Electricity consumption when idling (kW)) / (Battery Cycle Efficiency/100)

Tables

Table 1 Emission Factors Included in the Tool

Fuel Type	CO_2	CH_4	N_2O	NO_X	SO_2	CO	VOC	Unit
diesel	2.68000	0.00015	0.00018	0.05040	0.04536	0.01319	0.00168	kg/liter
petrol	2.34000	0.00057	0.00009	0.00732	0.00000	0.16268	0.03123	kg/liter
kerosene	2.58000	0.00011	0.00002	0.00871	0.00079	0.00553	0.00213	kg/liter
LPG	1.53000	0.00076	0.00000	0.00894	0.00000	0.03409	0.01475	kg/liter
natural gas	1.93000	0.01386	0.00015	0.04200	0.00001	0.00532	0.00224	kg/Nm3
fuel oil	2.68	0.00	0.00	0.05	0.05	0.01	0.00	kg/liter

Table 2 Carbon Content of Different Fluids

	Default Oil:Water (O:W) Ratio	Organic Additives	Organic Content of Waste Fluid
Spud mud	0.0 %	2.0%	0.5%
Silicate fluid	0.0%	2.0%	0.5%
Glycol/inhibitive WBM	0.0%	15%	1.0%
NAF/OBM	80%	5.0%	2.0%
Dispersed mud	0.0%	2.0%	0.5%
Formate fluid	0.0%	25%	1.0%
Brine	0.0%	2.0%	0.5%

Table 3 Emissions from End Disposal

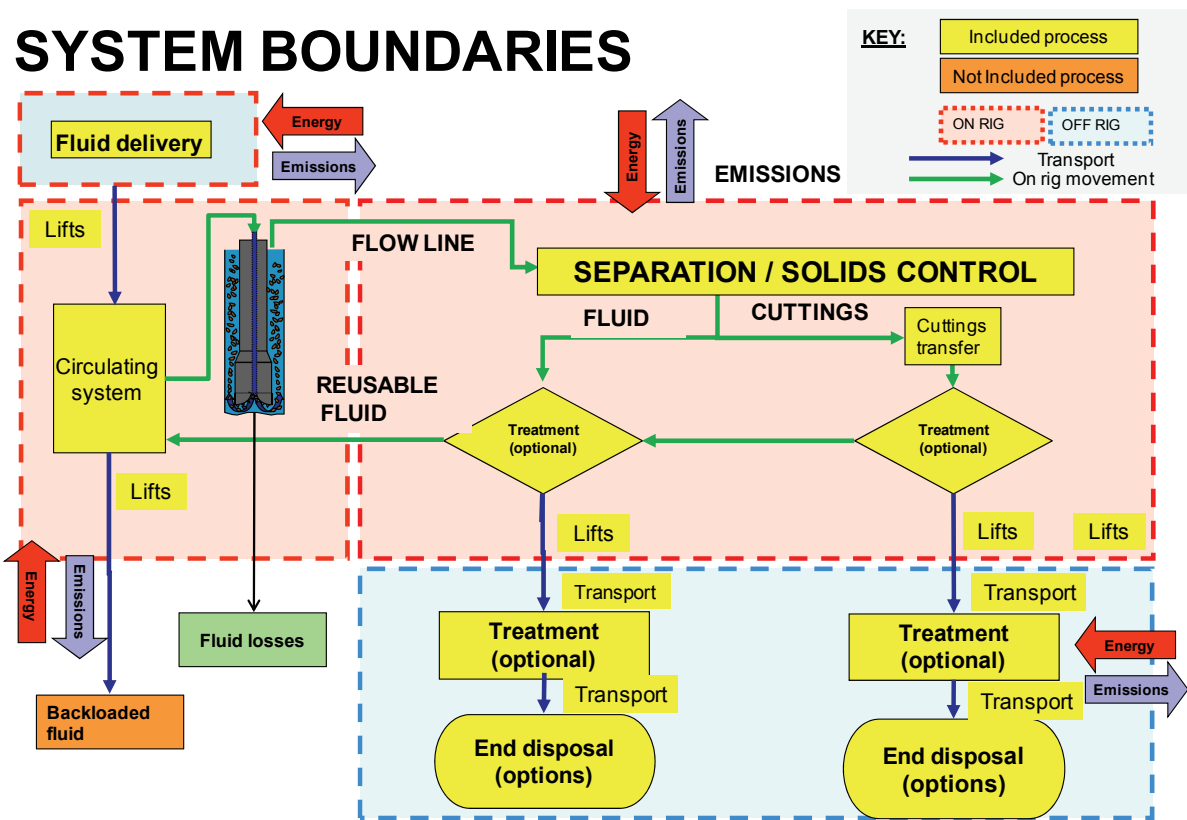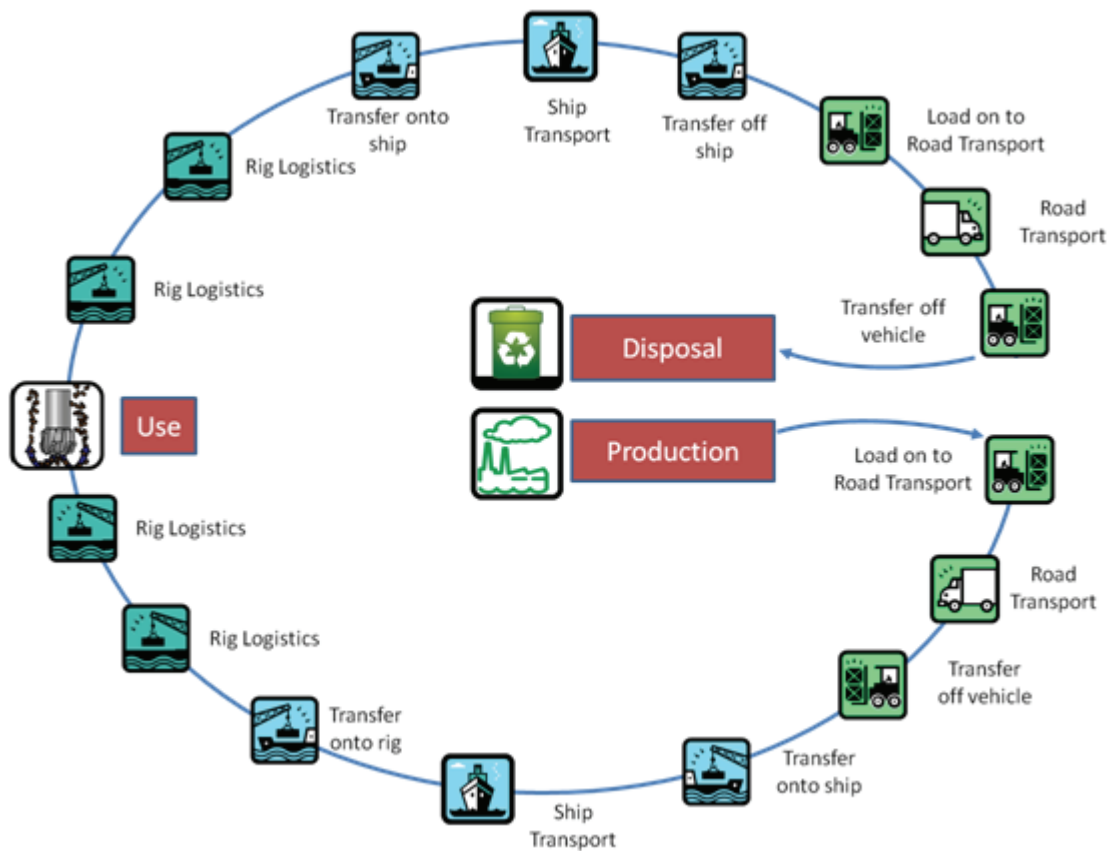|	Emissions (%)	
	CO_2	CH_4
Landfill	75%	25%
Burial	25%	75%
Land application	100%	0.0%
Discharge to sea	80%	20%
Construction materials	0.0%	0.0%
Down hole injection	0.0%	0.0%

Figures

SYSTEM BOUNDARIES

Figure 1 System boundaries

Figure 2 Logistics

Figure 3 Layout of the Input Section for Rig Operations (Circulating System)

Carbon Footprint Menu   Setup   Logistics & Processes   Carbon Footprint Calculator - Summary Report

Operation	**Hello Again, Hello World**		Prepared by Jonathon Gatliff	1-Sep-200
Material Used / Generated / Transported	6,923	[ur ton]	Energy Use	237,711 [kWh]
Total Emissions	3,430,737	CO₂ Eqv [kg]	Energy Cost	12,753 [US$]

Waste Management Plan

Well Section	Cuttings				Waste Fluids			
	Cuttings [ur ton]	Treat on Rig	Treat Offsite	End Disposal	Waste Fluids [ur ton]	Treat on Rig	Treat Offsite	End Disposal
17 1/2		drying	no treatment	discharge to sea		no treatment		discharge to sea
12.25		drying	no treatment	discharge to sea		no treatment		discharge to sea
8.5		no treatment	thermal treatment	landfill			fixation / stabilizatio	landfill
6		no treatment	thermal treatment	landfill			fixation / stabilizatio	landfill
completion								

CO2 Equivalent Emissions

All Processes — Loading & Transport Processes

Air Emissions and Energy Use Summary

Energy Source	Total / kWh	CO₂ / kg	CH₄ / kg	N₂O / kg	NOX / kg	SOX / kg	VOC / kg	CO / kg
grid	5,710	12,826.46	46.11	0.94	260.04	109.31	11.44	49.34
diesel	146,169	391,731.70	22.10	27.01	7,346.89	6,630.21	1,927.67	245.56
kerosene	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LPG	4,272	6,536.11	3.24	0.00	38.18	0.00	145.62	62.99
natural gas	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	156,150	411,094	71	28	7,645	6,740	2,085	358

Top 10 – Energy Use Processes

Process	Energy Use / kWh	CO₂ / kg
Load Out - Ship Transport	109,468	24,562
Pumping	30,692	51,077
Backload - Onto Ship	13,085	3,353
Cuttings Slurrification	12,751	31,458
Thermal Treatment	10,545	28,898
Backload - Ship Transport	9,971	2,237
Load Out - Road Transport	9,009	24,001
Load Out - Onto Ship	6,857	1,831
Cuttings Transfer	2,190	6,002
Load Out - Off Truck	1,680	3,406

Top 10 - CO₂ Equivalent Emissions

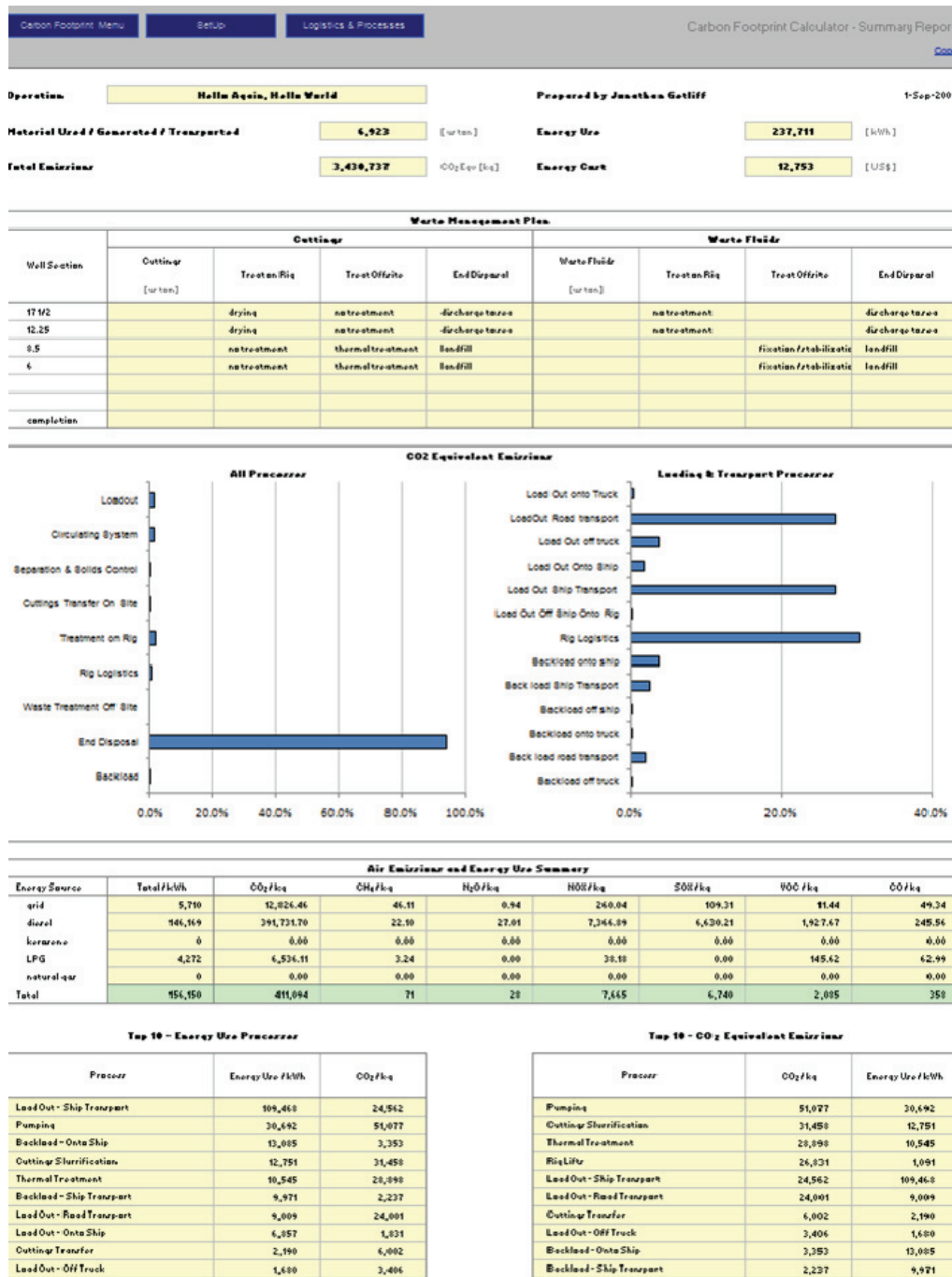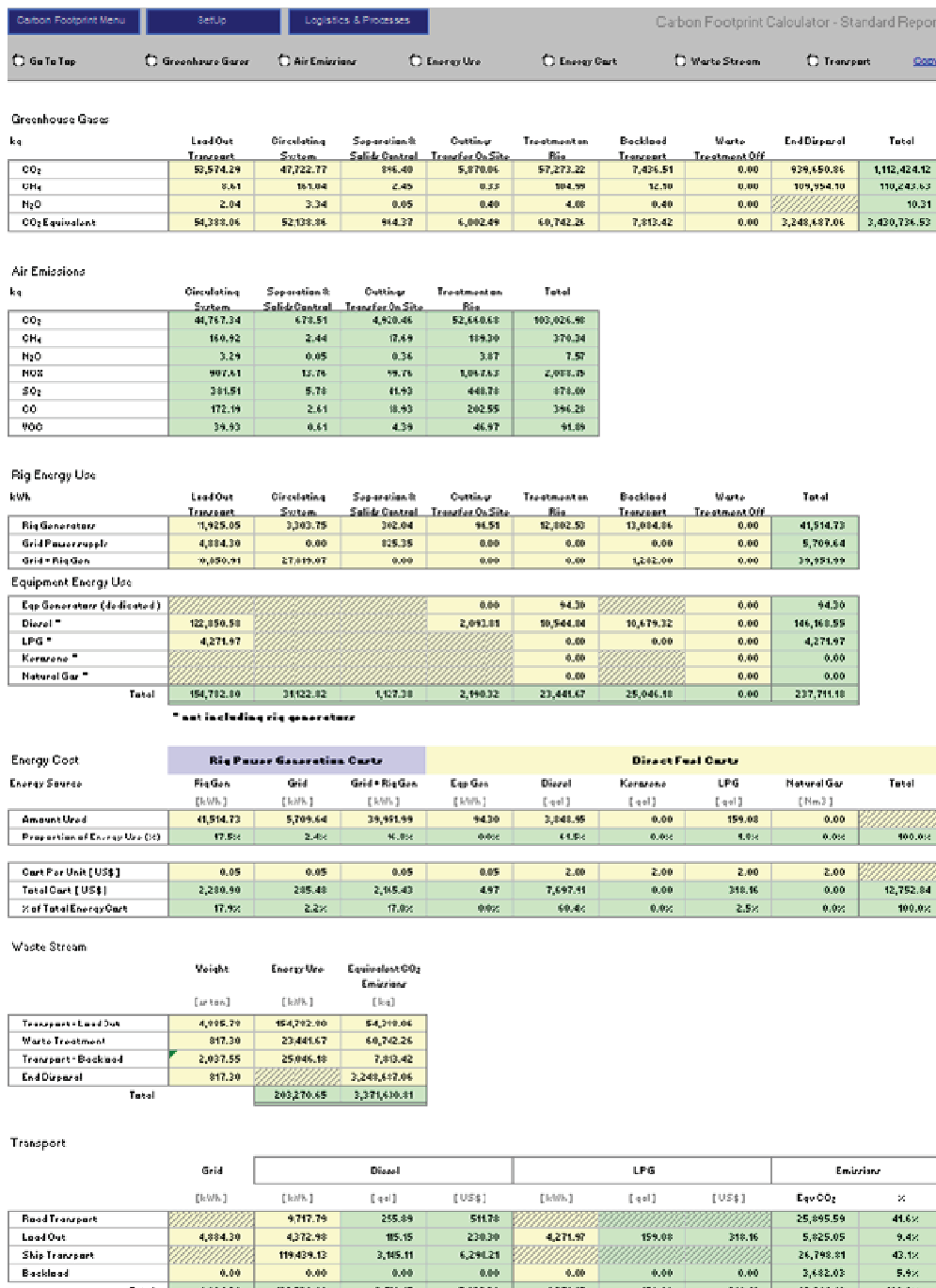| Process	CO₂ / kg	Energy Use / kWh
Pumping	51,077	30,692
Cuttings Slurrification	31,458	12,751
Thermal Treatment	28,898	10,545
Rig Lifts	26,831	1,091
Load Out - Ship Transport	24,562	109,468
Load Out - Road Transport	24,001	9,009
Cutting Transfer	6,002	2,190
Load Out - Off Truck	3,406	1,680
Backload - Onto Ship	3,353	13,085
Backload - Ship Transport	2,237	9,971

Figure 4 Standard Carbon Footprint Report

Figure 5 Summary Carbon Footprint Report