The Net Carbon Footprint Model: Methodology (Public)

Shell Global Solutions US Inc.

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Adom, Felix K GSUSI-PTS/GX

Verma, Akash GSNL-PTS/GX

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Executive summary

In November 2017 Shell announced its ambition to reduce the Net Carbon Footprint of its portfolio of energy products with the aim of being in step with society by 2050, and with an interim ambition of a reduction of around 20% by 2035[1]. In April 2020, Shell announced its intent to accelerate the Net Carbon Footprint ambition to align with the stretched goal of the Paris Agreement resulting in the announcement of an increased ambition. Shell now aims to reduce the Net Carbon Footprint of the energy products it sells by around 30% by 2035 and 65% by 2050.

Shell's portfolio of energy products comprises liquid fuels (including GTL and biofuels) for transport, pipeline gas and LNG for power and transport, and electricity from conventional and renewable sources (i.e. solar and wind).

Shell has developed a methodology for the quantification and tracking of the Greenhouse Gas (GHG) emissions from the entire life cycle of these products taking into account not only products produced by Shell, but also all products ultimately sold by Shell, including those sourced from 3rd parties. This report sets out that methodology, its boundary, scope and assumptions.

The methodology has been implemented within a model which calculates the Net Carbon Footprint of the portfolio of energy products sold by Shell on the basis of gCO_2e per megajoule (MJ) of energy delivered to, and consumed by, the end-user. The model is structured around the principal supply chains within the portfolio of energy products; more specifically the following supply chains and steps in the product lifecycle are included:

- Liquid fuels: (i) crude oil production, (ii) transportation of crude oil (pipeline/shipping), (iii) refining, (iv) distribution of oil products, and (v) end-use of oil products in the transport sector.
- Pipeline gas: (i) gas production, (ii) transportation of gas via pipeline, and (iii) end-use of gas in power generation.
- LNG: (i) gas production, (ii) transportation of gas via pipeline, (iii) liquefaction, (iv) shipping of LNG products, (v) regasification of LNG in recipient terminals, (vi) local distribution of gas, and (vii) end-use of gas in electricity/heat generation.
- GTL: (i) gas production, (ii) transportation of gas via pipeline, (iii) gas-to-liquid processing, (iv) shipping of GTL products, (v) local distribution of GTL fuel products, (vi) end-use of fuel products in the transport sector.
- Biofuels: (i) production, (ii) transportation (domestic/shipping), (iii) distribution and (iv) end-use in the transport sector.
- Electricity from solar, wind, and other fossil and renewable sources, expressed as fossil energy equivalent.
- CO_2 reductions: the model also assesses the impact of CO_2 reductions from carbon capture and storage (CCS) projects and nature-based solutions (NBS).

Non-energy products such as chemicals, lubricants and bitumen are outside the scope of the NCF because the end-use of these products is generally not to be consumed as fuel.

[1] For further details of Shell's NCF Ambition see; https://www.shell.com/energy-and-innovation/the-energy-future/what-is-shells-net-carbon-footprint-ambition/faq.html

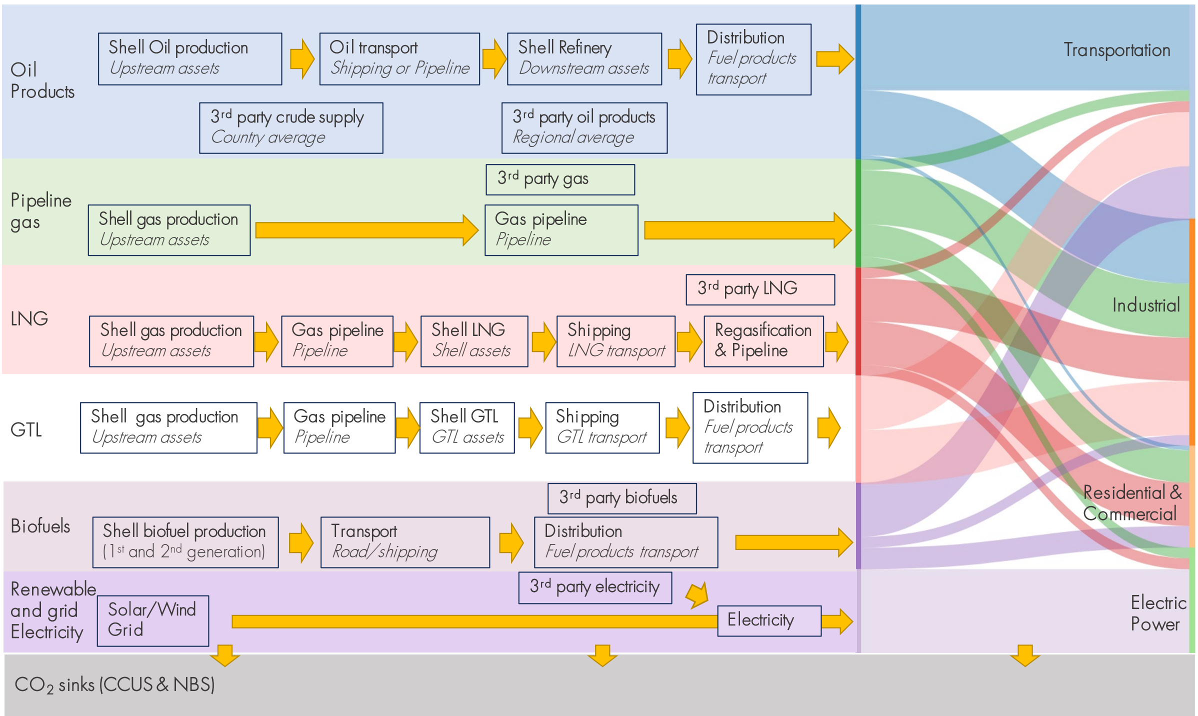

Figure 1 - Supply chains included in Shell's NCF

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1. Introduction

1.1. Goal of the Net Carbon Footprint (NCF) assessment

The goal of Shell's Net Carbon Footprint (NCF) assessment is to provide an annual measure of the lifecycle emissions intensity of the portfolio of energy products sold by Shell[2]. The intended use of the metric is to track progress in reducing the overall emissions intensity, on a lifecycle basis, of Shell's product portfolio, as described in Shell's Net Carbon Footprint Ambition[3].

It is of primary importance that the NCF value responds correctly to year-on-year changes in the make-up of Shell's portfolio and to changes in the energy efficiency of Shell's operations. It must also be demonstrated that there are no material omissions within the scope of the analysis in order that the intensity can be meaningfully compared with society's GHG targets.

1.2. Overview of the methodology

To calculate the NCF it is necessary to first establish the emissions intensity for each of the energy product supply chains in Shell's portfolio (Figure 1); this is done using established lifecycle analysis principles and includes both the emissions associated with bringing products to market and the emissions associated with their use (Figure 2). The supply chain intensities are then aggregated into a portfolio average; weighted by the delivered energy. Finally, emissions captured in sinks are deducted to give the NCF value.

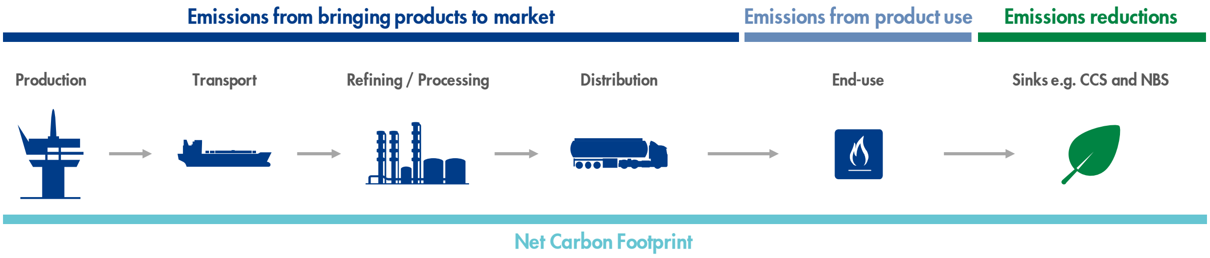

Figure 2 – Indicative supply chain: An illustration of the emissions sources and sinks included in the Net Carbon Footprint.

The NCF is based on the characteristic lifecycle emissions for each energy product and includes the principal process steps in transporting and transforming the product from the well to the end-user. As such, it is insensitive to the point in the supply chain at which a sale is made, since the intensity will always be based on the full GHG lifecycle emissions of an energy product. Only net physical transfers are included, and trading activity that doesn't involve a physical commodity is excluded. The fate of products after physical transfer is outside of Shell's control, so the NCF doesn't differentiate between, for example, a fuel sold to a customer at a retail site who will use it immediately and a fuel sold to an IOC, distributor or utility which may be resold again before it is finally used.

[2] Specifically, the products sold by the company and its subsidiaries, as well as Shell's share of products sold by its joint ventures and associates, and for LNG, including Shell's share of LNG sold from its investment in financial assets available for sale.

[3] https://www.shell.com/energy-and-innovation/the-energy-future/what-is-shells-net-carbon-footprint-ambition.html

Non-energy products such as chemicals, lubricants and bitumen are outside the scope of the NCF because the end-use of these products is generally not to be consumed as fuel.

1.3. Scope and boundaries of the NCF analysis

In general, calculating the Well-to-Wheels (WtW) life cycle emissions of a product will include the acquisition of raw materials, transport of raw materials, processing of materials for products, transport of products to end-users, and utilisation of products and disposal of waste streams (Figure 2). We consider only Shell equity based operational emissions, excluding the energy or GHG emissions associated with construction or decommissioning of fuel production, transportation, or end-use facilities. There are two reasons for this. First the available data is often uncertain, secondly the impact of these additional energy requirements on the total fuel pathway balance is generally small and within the range of uncertainty of the total estimates when amortized over the life cycle of these facilities.

Our goal is to assess the Net Carbon Footprint of all energy products sold by Shell, which includes material produced and processed by Shell and materials produced and processed by others. For example, in 2016, for every barrel of oil extracted by Shell, 1.6 barrels are processed in refineries and 3.9 barrels of oil products are sold. Similar complexity exists in the other supply chains included in the model.

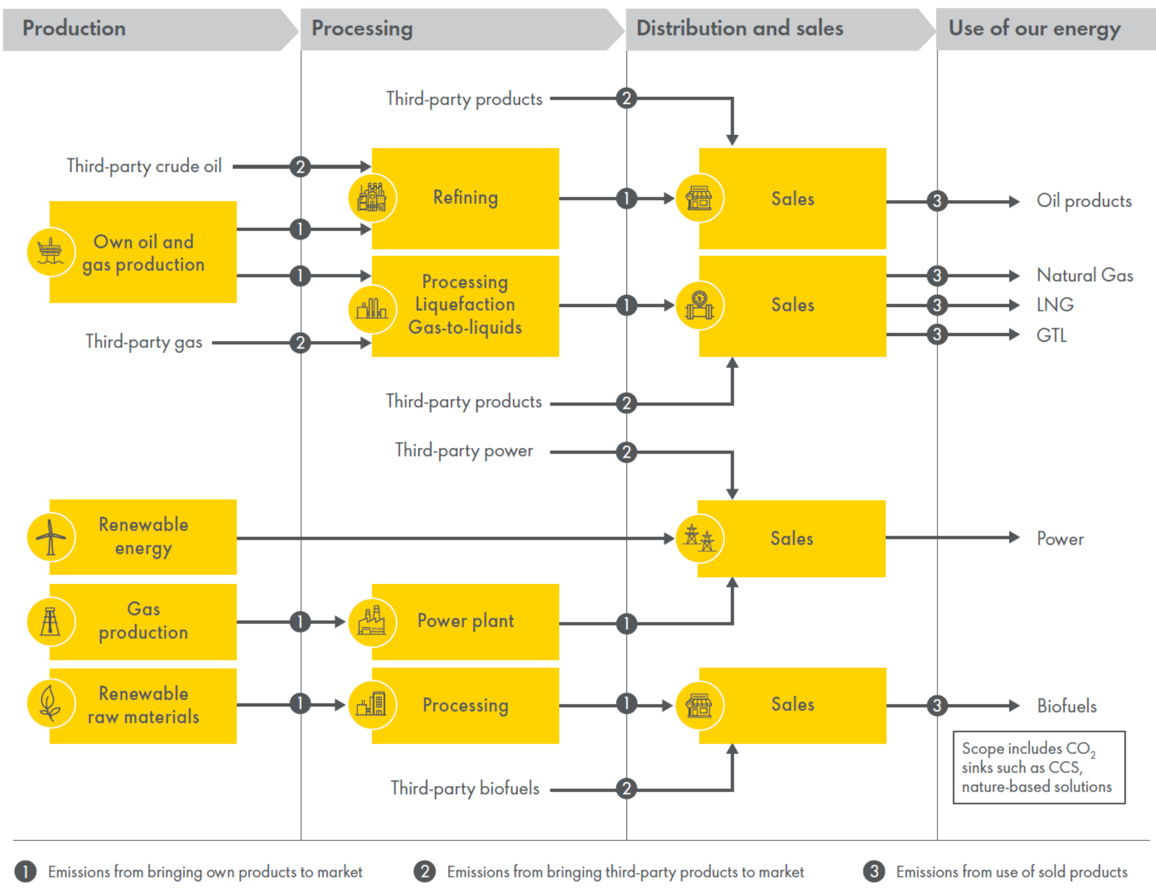

Figure 3 - An overview of Shell's portfolio from three perspectives: Production, Processing and Sales

The inclusion of third-party feedstocks and products at different stages within the model means that the WtW GHG intensity can be considered from three perspectives, as illustrated in Figure 3:

(i) **Production**: Energy products (mostly oil and gas) produced by Shell only.

(ii) **Processed**: Energy products processed by Shell using feedstocks produced by Shell and feedstocks sourced from 3rd parties.

(iii) **Sales**: All energy products ultimately sold by Shell, including Shell's own production and products sourced from 3rd parties.

The Net Carbon Footprint is defined as the weighted average lifecycle carbon intensity of the portfolio of energy products sold by Shell. This is the equivalent of the 'Sales' perspective described above.

WtW calculations in the NCF model were conducted following ISO standards [1] for life cycle analysis with the following clarifications:

- The NCF applies only to the lifecycle emissions intensity of the energy products supplied by Shell.
- Chemicals (including lubricants and bitumen) are not energy carriers and are therefore omitted from the scope of the NCF.
- The Net Carbon Footprint methodology uses the language of "well-to-wheel" emissions but, in fact, not all the emissions can be traced back to the well. Emissions associated with producing fuel and transporting it to Shell assets are not included, nor are emissions associated with the production and transport of fuels to our electricity suppliers, because insufficient data are available to allow these emissions to be calculated. The omission is not considered to be material[4].

These exclusions do not affect the use of the NCF as a metric for monitoring year-on-year changes in the emissions intensity of Shell's energy product sales. A more exhaustive analysis might make small changes to the absolute NCF value but, most importantly, the NCF metric achieves the goal of responding to changes in the make-up of Shell's portfolio and to changes in the energy efficiency of Shell's operations.

1.4. Functional units

Lifecycle intensities should be compared and combined on the basis of functionally equivalent units. Different products have different uses and it is difficult to derive a single measure for their utility to their respective end use. Oil products are mostly used in transportation, where the utility to the end-user is measured in terms of distance travelled or load carried by a vehicle. Natural gas is mostly used for power generation and heating, where the utility to the end-user is the energy content of the product as a fuel. Electricity has many different applications.

The functional unit used for the NCF calculation is energy consumed by the end-user. For example, the lifecycle carbon intensity of pipeline natural gas is expressed as gCO_2e/MJ including GHG emissions from its combustion by the end-user, e.g. power generation. However, the power plant efficiency and any subsequent losses in the distribution of the generated

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[4] Combustion typically accounts for most of the life cycle emissions from hydrocarbon fuels and emissions from the use of these fuels at Shell facilities are captured in Shell's Scope 1 and 2 emissions. The emissions from the end-use of Shell products are the most significant contribution to the NCF from hydrocarbon fuels. Therefore, the emissions associated with the production, processing and transportation of fuels used at Shell facilities amount to a small part of a small part and omitting them does not make a material difference to the NCF value.

electricity are considered to be outside the scope. Similarly, for oil products the emissions of combustion are taken into account on a per-MJ basis, but differences in the end-use efficiency of different vehicles is out of scope.

Electricity is treated differently because of its greater utility. A unit of electricity may be used directly whereas a unit of fossil energy (oil or gas) requires further conversion before it is useful. The portfolio is dominated by oil and gas, so electricity is converted to an amount of "fossil fuel equivalent" energy to account for its greater utility. This is described in more detail in Section 7.1.

1.5. Data requirements for the NCF calculation

To calculate Shell's Net Carbon Footprint, the reported emissions and production data from Shell's assets are used along with Shell's reported product sales. Emissions data from Shell's Upstream and Downstream assets are major inputs to the calculation, along with energy product sales volumes from the various Shell businesses. Data sources for each line of business are explained in more detail in the following chapters. Data for non-Shell products and processes are taken from the public domain, where possible, and the sources are documented in the following chapters.

1.6. Assurance of the Net Carbon Footprint model and results

Shell's Net Carbon Footprint values are expected to be independently assured[5] before their annual publication. The assurance process will confirm that the methodology described in this document has been applied and confirm that Shell has appropriate internal controls in place for critical processes such as data collection and maintenance of the NCF model.

1.7. Key Assumptions made in the Lifecycle Analysis

The tracking of Shell and 3rd party hydrocarbon flows between the upstream, midstream and downstream operations rapidly becomes very complex. In order to make the calculation of the carbon intensity along the value chains more manageable, some simplifications and assumptions need to be made:

OIL

- Where oil and gas are co-produced at an asset, emissions are allocated by the energy content of the products, so that oil and gas co-products have the same intensity in $kgCO_2e$/boe or gCO_2e/MJ. The oil produced is routed to the OIL supply chain.
- When assessing Shell production, we assume that crude oil production goes first into our equity refining capacity and then the gap between Shell's production and the refinery intake is filled with 3rd party crude oil with a country-average carbon footprint.
- When assessing Shell processing, likewise, we assume that the crude intake of our refineries is first supplied from Shell production and any gap is filled with 3rd party crude oil with a country-average carbon footprint.
- When assessing Shell sales, we assume that oil products are first supplied by the output of Shell refineries in the region and any gap between Shell's production and sales is filled with products sourced from 3rd parties with a with a country-average carbon footprint.

[5] Assurance statements for published Net Carbon Footprint values can be found here: https://www.shell.com/sustainability/sustainability-reporting-and-performance-data/performance-data/greenhouse-gas-emissions.html

- The country-average carbon footprint of non-Shell oil production is taken from a journal publication based on the OPGEE model [2].
- Information about the carbon intensity of 3rd party activities is not generally available for reasons of commercial confidentiality. Due to this lack of information, the CIs of 3rd party refineries are assumed to be the same as that of the weighted average of Shell's refineries in the same region. For regions where there are no Shell refineries, a virtual refinery representing a global Shell refinery average is assumed.
- The refinery diet of 3rd party refineries is generally assumed to be the same as Shell refineries' diet in each region.

GAS

- Where oil and gas are co-produced at an asset, emissions are allocated by the energy content of the products, so that oil and gas co-products have the same intensity in $kgCO_2e$/boe or gCO_2e/MJ. The gas products are routed to the GAS/LNG/GTL/ELEC supply chains.
- Shell produced natural gas may be routed to pipeline gas, LNG, GTL or electricity generation. Upstream gas production is first routed to Shell LNG, GTL and power plants and any surplus production is routed to pipeline gas or LNG, as appropriate to each country of production.
- Gas produced by 3rd parties is also marketed by Shell; these volumes have not historically been disclosed are now disclosed as a single figure for global 3rd party gas sales in Shell's Sustainability Report beginning in 2019. These volumes are included in the NCF.

LNG

- When assessing Shell processing, we assume that all feed gas for our LNG facilities is taken at the average intensity of Shell gas producing assets located in the same country and any gap between Shell's production intake is filled with 3rd party gas with a country-average carbon footprint. Unlike oil, there is no equivalent data source that allows us to estimate the intensity of 3rd party gas production so, in the absence of country-specific data, non-Shell gas is assumed to have the same intensity as Shell gas.
- LNG sales are analysed as a single global region. The assumption is that non-Shell LNG is produced at the same intensity as world-average Shell LNG.

GTL

- When assessing Shell processing, we assume that all feed gas for our GTL facilities is taken at the average intensity of Shell gas producing assets located in the same country and any gap between Shell's production intake is filled with 3rd party gas with a country-average carbon footprint.
- Only GTL energy products are included in the NCF; "chemical" GTL products such as lubricant base oils and waxes are excluded.

BIOFUELS

- Biofuel sales are disaggregated by product, feedstock, and region of production, assuming a characteristic regional-average intensity taken from renewable fuels regulations in Europe and the United States.

- The BIOFUEL supply chain excludes land use change (LUC) emissions to avoid the possibility of the NCF value changing as a result of legislated LUC intensities rather than by any action of Shell.

SOLAR and WIND

- SOLAR and WIND assets are broken out as separate supply chains in the model. Conventional power generation from fossil fuels is dealt with in the ELECTRICITY supply chain.

ELECTRICITY

- When assessing Shell power generation (gas-fired or co-fired), we assume that all feed gas for our power plants is taken at the average intensity of Shell gas producing assets located in the same country and any gap between Shell's production intake is filled with 3rd party gas with a country-average carbon footprint.
- The Shell share of electricity sales, regardless of whether the electricity is generated by Shell or a 3rd party are included in the NCF. Electricity volumes sold in power markets are included except for pure trading activity.
- In order to give electricity an appropriate weight in the calculation of the portfolio-average carbon intensity, a conversion factor is used to convert the electricity to fossil energy equivalents. The conversion factor is the average amount of total primary energy used per unit of electricity generated in the world. The NCF model conservatively chooses to derive a time-dependent ratio of power and fossil energy use from the IEA's 2017 ETP "World – 2°C scenario", with power to primary energy ratios ranging from 0.40-0.50 on LHV basis from the present to 2050.

ALL PATHWAYS

- Shell assets report Scope 1 operational emissions (incl. fuel combustion, fugitives, flaring and venting) and account for Scope 2 emissions from imported electricity. A true well-to-wheel analysis would include Scope 3 emissions associated with producing fuel and transporting it to the asset and also make allowance for the production and transport of fuels to the electricity supplier, together with any distribution losses. Business reporting and planning data does not include sufficient detail to allow these to be calculated. The omission is considered negligible compared to the Scope 3 emissions associated with the end-use of fossil energy.
- Shell business reporting data includes oil production volumes from refineries but not oil properties. In this analysis, it is assumed that 1 bbl (a volume) is equivalent to 1 boe (a fixed amount of energy). The density, higher and lower heating value, and carbon fraction of all hydrocarbons is taken from Table 3-8 of the API Compendium [3].
- Shell business reporting data includes gas production volumes but not gas composition. In this analysis, it is assumed that all gas produced has the same density and heating value.

The application of these rules ensures that:

- By preferentially using Shell feedstock for Shell processes, the NCF value responds maximally to any improvement or worsening of the emissions intensity of Shell operations. It is not possible to influence the NCF value by, say, diverting high intensity oil to non-Shell refineries.
- The apportionment of oil and gas between Shell refineries or gas-processing plants (LNG, GTL or powergen) is automatic – pro rata with in-country feedstock demand. It is not possible to influence the NCF value by, say, directing only low-intensity feedstock to high-intensity processing plants.
- Where there are no data on the intensity of non-Shell products, the assumption that non-Shell products have the same average intensity as Shell products in the region makes it impossible to influence the NCF value by, say, diluting Shell sales with low-intensity non-Shell products.

1.8. Structure of the report

The individual energy product supply chains are described in the following chapters. Each chapter has the same underlying structure:

- A description of the supply chain and the elements included in the lifecycle analysis
- A description of the input data sources: Shell and non-Shell
- A high-level description of the methodology
- The implementation of the methodology – first, for a single illustrative WtW pathway (e.g. one oil well, one refinery), then for realistic pathways (e.g. multiple oil wells per refinery).

Lastly, the report describes how the Net Carbon Footprint value is calculated from the individual supply chain intensities, adjusted for CO_2 sinks.

2. Oil Portfolio

2.1. The structure of the oil portfolio calculation

Figure 4 shows the steps in the analysis of the WtW GHG intensity for the oil supply chain.

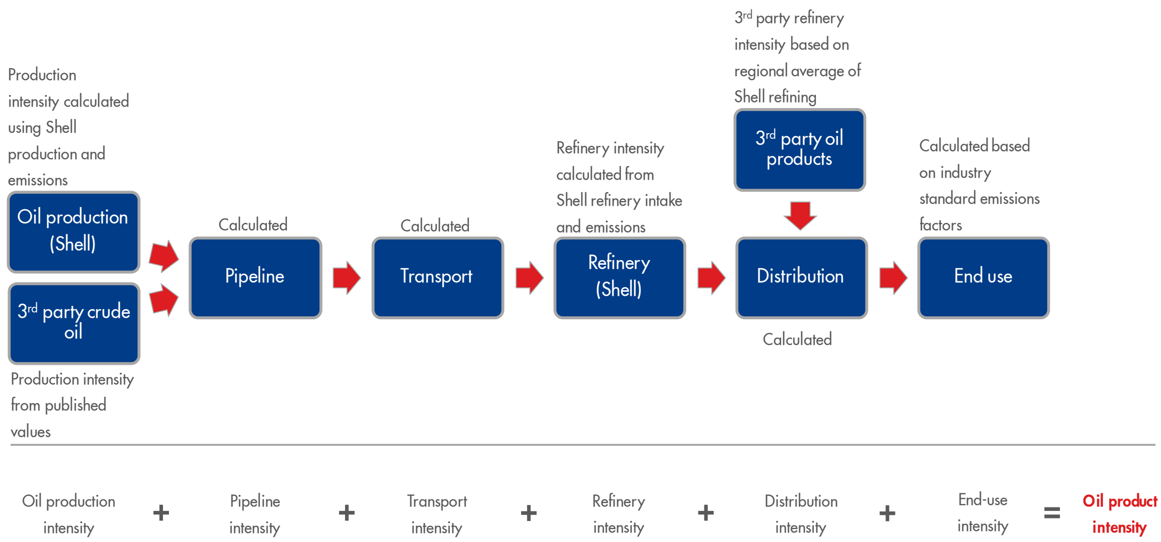

Figure 4 – The OIL supply chain

The NCF calculation works through a list of Shell oil production assets, described by:

- Oil production intensity by year (in kgCO_2e/boe)
- Oil production volume by year (in kboe/day)
- The pipeline distance to the oil export terminal (in km).

It is also necessary to know the intensity of non-Shell oil production processed by Shell refineries:

- Oil production intensity by year (in kgCO_2e/boe) by country

The NCF calculation also works through a list of Shell oil processing assets, described by:

- Oil processing intensity by year (in kgCO_2e/boe)
- Oil processed volume by year (in kboe/day)
- The refinery efficiency by year (in $MJ_{crude}/MJ_{product}$)
- The refinery diet – the percentage of crude intake from a list of up to 40 countries.

The lifecycle calculation is completed with the following parameters:

- Transport & distribution between refinery and point of sale.
- End-use (tank-to-wheel) intensity.

2.2. Input data sources for the Oil portfolio calculation

Emissions and production data for upstream production assets and downstream refinery assets are taken from Shell business reporting data. In upstream operations, both oil and gas assets produce oil or condensate as feedstock for refineries. Therefore, the CIs of oil and gas assets are expressed as kgCO_2e/boe which are then converted to CO_2e emissions per MJ of hydrocarbons produced. This means the emissions are allocated between oil and associated gas (or condensate and gas) on an energy basis for coproducing assets. Actual refinery intake and processed volumes are used to calculate the refinery efficiency[6]. Refinery diets for Shell Group refineries were obtained from the Downstream business. Oil products for sale are from Shell's Annual Report and Form 20-F (minus the biofuel content of sales to avoid double counting with the BIOFUEL sales portfolio).

Following production, oil can be transported via pipeline within the country or region. Assumptions on pipeline distance can be found in APPENDIX 2. The emissions intensity of pipeline transport was taken from the GREET model (2018), 0.96 gCO_2e/MJ/1000km [4].

The quantity of oil shipped inter-regionally in mboe/d was taken from the IEA's 2014 Oil Medium-Term Market Report [5]. To find an estimate of the shipping distances for the transport of oil between the regions, the most active shipping and receiving oil terminals were identified in each region along with their closest port. The shortest distance between ports was calculated using a shipping distance calculator [6]. More details about the oil transport sector can be found in APPENDIX 2. The emissions intensity of oil shipping was taken from the GREET model (2018), 0.21 gCO_2e/MJ/1000km [4].

For distribution of oil products from the refinery, a generic intensity is used – currently 0.63 gCO_2e/MJ, taken from a European (JEC) study [7].

For Tank-to-Wheel (TtW) CI, the transport sector is assumed to be the end-user of oil. The functional unit of the analysis is MJ of energy supplied, so the efficiency of the end-use is immaterial. Most of the end-use emissions result from conversion of the carbon content of the fuel to CO_2 together with methane emissions and N_2O emissions associated with combustion in engines. The Tank-to-Wheel (TtW) CI is a weighted average value calculated from average refinery processing outturn (gasoline, diesel, kerosene and fuel oil production) and API Compendium emission factors for each fuel type - currently 72.76 gCO_2e/MJ [3].

2.3. The methodology for the OIL supply chain

2.3.1. Oil Processed calculation

The Processed calculation for the oil portfolio includes both Shell and 3rd party crude oil processed in Shell's refineries. The demand of crude oil from each producing country is calculated based on the refineries' diet and production rates.

The OIL Processed calculation is driven by a list of Shell refinery assets. The final delivered energy corresponds to the amount of oil processed in Shell refineries. That oil may be Shell's own production or, if there is insufficient supply from a country, topped-up with non-Shell oil production.

[6] If refinery efficiency is not known, an average of 1.10 MJ/MJ is used (JEC = 1.08 for gasoline, 1.1 for diesel. GREET = 1/88.6% for gasoline, 1/90.9% for diesel).

Step 1: the first step is to derive the country-average intensity of Shell oil production in each source country as shown in Figure 5[7]. We also need to know how much oil is demanded from each country so that we can share out the Shell production between all consumers.

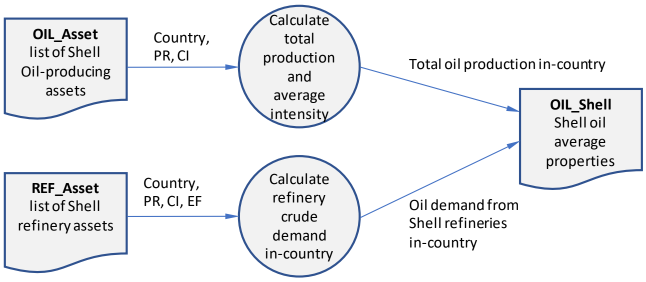

Figure 5 - OIL balance calculation – country-average oil production intensity

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Step 2: the next step is to evaluate the intensity of production at each refinery in turn. The methodology followed is illustrated in Figure 6.

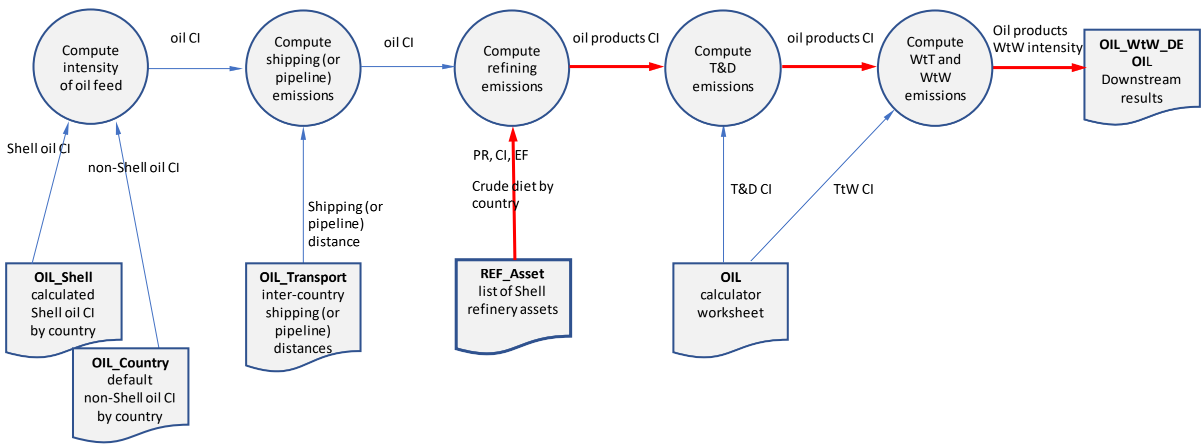

Figure 6 - OIL Processed calculation data flow diagram

- For each Shell refinery, we take the amount of crude oil processed and use the refinery crude diet to determine which countries supply the crude.
- From Step 1, we know the total crude demand of all Shell refineries for crude from each source country. For each source we supply as much Shell crude as possible, sharing out the Shell production between all the consumers. Any shortfall is made up of non-Shell crude at a characteristic intensity for each oil-producing country.
- For each source, the shipping distance from the country of oil production to the refinery is looked up.
- The WtW pathway GHG intensity analysis is completed with transport & distribution and end-use intensities. (These are the same for all destinations.)
- A weighted average WtW intensity for the refinery is calculated over all sources of crude.

[7] For definitions of the abbreviations used in this figure see Table 1.

2.3.2. Oil Sales calculation

The OIL Sales calculation is driven by a list of oil sales by region, which sets out the final delivered energy in each region. Volumes of refinery products sold by Shell in each region are taken from Shell's Annual Report and Form 20-F (adjusted to exclude biofuels, which are handled in the BIOFUEL supply chain).

It is assumed that the difference between the volumes of refinery products produced by Shell and those sold by Shell are made up by products produced by 3rd party refineries, purchased and re-sold to Shell's customers. Due to the lack of information about CIs and diet for 3rd party refineries, an estimate is made of the regional average refinery CIs and diet based on Shell refineries in the sales region. (For Oceania, where there are oil products for sale but no Shell refinery, the global average refinery CI is applied, and it is assumed that the crude diet is the same as Asia-Pacific.)

When considering the production of 3rd party oil products, each crude source listed in the refinery diet is assumed to be 100% non-Shell crude (because Shell refineries have already consumed the available Shell crude production).

Oil transport mode and distance are estimated, taking a single destination country as representative of shipping distances for the region (Europe=Netherlands, Asia-Pacific=China, America=United States, Africa=South Africa, Oceania = New Zealand).

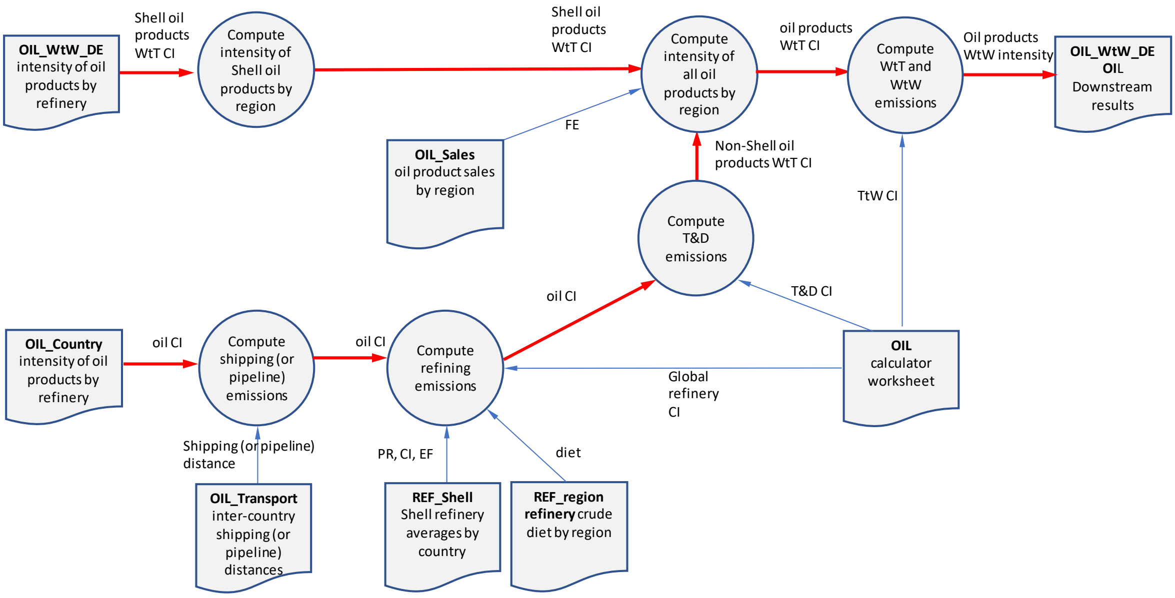

Figure 7 - OIL Sales data flow diagram

For each sales region, the WtW intensity is calculated over the pathway shown in Figure 7.

- For each sales region we obtain the average refinery crude diet from regional refinery crude diet list.
- We then calculate the weighted average WtT intensity of crude from each Shell refinery supplying the sales region.
- We know the amount of crude that can be supplied from Shell refineries. The shortfall is made up from non-Shell crude supplied within the sales region.
- Any shortfall is made up of non-Shell crude at the characteristic intensity for each country.
- The non-Shell crude is refined at an intensity equal to the average intensity of Shell refineries in the sales region, as calculated above.

- For each crude source, the shipping distance from the country of oil production to the representative sales location is looked up.
- The WtW pathway GHG intensity analysis for non-Shell crude is completed with transport & distribution and end-use intensities.
- A weighted average WtW intensity for the sales region is calculated for Shell and non-Shell oil products.

2.4. Implementation of the calculation methodology for OIL

2.4.1. Acronyms, Abbreviations and variables

The list of core acronyms and abbreviations used in this section are given in Table 1.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	GHG Emissions in gCO_2e/MJ	15	WtT	Well to Tank
2	Au	Upstream asset	16	WtW	Well to Wheel
3	Ar	Refinery asset	17	LHV	Lower Heating Value
4	t	time	18	ref	Refining
5	p	Pipeline distribution	19	veh	vehicle
6	pr	Upstream production of oil	20	shp	Shipping mode
7	D	Distance	21	$Port$	Portfolio
8	exp	Export of oil	22	dst	distribution of fuel
9	cu	Upstream country	23	cr	Refining country
10	P	Oil or Refinery output	24	C	Oil consumption
11	s	Shell asset	25	$\bar{s}$	non-Shell asset
12	W	Weight fraction	26	$pipe$	Pipeline mode
13	Rg	Refinery region	27	Ci	Carbon intensity in $kgCO_2e/boe$
14	Eff	Refinery efficiency	28	$sale$	Sales portfolio

Table 1 - Acronyms, abbreviations and variables used for Oil calculations

The above abbreviations can be used to derive the variables used in the model and in this report. Thus, $CI^{WtW}_{(Au,Ar),t}$ would mean WtW emissions in gCO_2e/MJ for oil produced by upstream assets Au and refined by downstream refinery assets Ar at time t. $CI^{pr}_{Ar,t}$ would imply emissions in gCO_{2e}/MJ related to production pr of oil that is used by refinery Ar at time t.

2.4.2. Lifecycle CI calculation

Shell has an equity share in multiple oil producing assets and refineries that are either operated by Shell or a third party. To assess the WtW and WtT emissions for a given pair of upstream asset or an average upstream asset (Au) and a downstream refinery or an average downstream refinery (Ar), the methodology followed by the model can be expressed as:

$$CI^{WtT}_{(Au,Ar),t} = (CI^{pr}_{Au,t} + CI^{p}_{Au} + CI^{exp}_{cu,cr} + CI^{ref}_{Ar,t}) * Eff^{ref}_{Ar} + CI^{dst} \qquad \text{(Eq. 01)}$$

$$CI^{WtW}_{(Au,Ar),t} = CI^{WtT}_{(Au,Ar),t} + CI^{veh} \qquad \text{(Eq. 02)}$$

Production

$CI^{pr}_{Au,t}$ is the upstream production related intensity in gCO_2e/MJ of oil produced. It is calculated as follows:

$$CI^{pr}_{Au,t} = \frac{Ci^{pr}_{Au,t} * 1000}{LHV_{oil}} \qquad \text{(Eq. 03)}$$

CI^{pr} may be a mix of Shell and non-Shell oil production, depending on the refinery diet. A factor of 1000 is used to convert kg to g.

Pipeline

CI^{pi}_{Au} is the upstream intensity in gCO_2e/MJ for transporting the oil from the oil producing asset to the export terminal in that country through a pipeline. This is currently not estimated in the model as the pipeline distances between the oil producing assets and the export terminals are not known and therefore set as zero, sensitivity analysis shows that omitting this pipeline distance does not have a significant effect on the NCF.

Export

CI^{exp} is also dependent on the combination of oil production and refining locations. Oil may be moved by pipeline or ship.

Refinery

$CI^{ref}_{Ar,t}$ is the emissions intensity in gCO_2e/MJ to process the oil in a refinery at a specific time t. This is calculated as follows:

$$CI^{ref}_{Ar,t} = \frac{Ci^{ref}_{Ar,t} * 1000}{LHV_{oil}} \qquad \text{(Eq. 04)}$$

where $Ci^{ref}_{Ar,t}$ is the emissions intensity of the refinery in $kgCO_2e/boe$. LHV_{oil} is the lower heating value of the oil as MJ/boe. A factor of 1000 is used to convert kg to g.

Distribution and End-use

CI^{dst} is the intensity for distribution of the finished product from the refinery to point of sale. It is assumed to be a constant (that is, time and asset independent).

CI^{veh} is the intensity in gCO_2e/MJ due to combustion of the finished product in vehicles.

2.4.3. Portfolio CI of refinery assets - Processed view

In this part of the model, the WtW emissions of a portfolio of refinery assets are calculated. A Shell operated refinery can use oil from one or more countries as part of its crude diet. Further, the oil from a given country can be sourced from a Shell upstream asset or from non-Shell upstream assets. The methodology used to calculate upstream emissions associated with the production of oil are therefore different for this part of the model. These emissions are $CI^{Pr}_{Ar,t}$ instead of $CI^{Pr}_{Au,t}$. In other words, these emissions are refinery and time specific instead of country and time specific.

The Shell component of upstream $CI_{cu,t}^{pr,s}$ refers to the emissions in gCO_2e/MJ due to production (pr) of oil by Shell assets (s), in country cu at time t. Allowing for pipeline emissions to the port of export CI_{Au}^{p}, these are calculated as follows:

$$CI_{cu,t}^{pr,s} = \sum_{Au}(CI_{Au,t}^{pr,s} + CI_{Au}^{p}) * W_{Au,t}^{s} \qquad \text{(Eq. 05)}$$

where Au signifies upstream assets of Shell, s, in country cu. The component $CI_{Au,t}^{pr,s}$ is calculated according to Equation 03. $W_{Au,t}^{s}$ is the fraction (expressed in %wt) of Shell's oil in country cu that belongs to asset Au.

The non-Shell component of upstream emissions is represented $CI_{cu,t}^{pr,\bar{s}}$. The notation $\bar{s}$ is used to represent non-Shell assets. The values are in $kgCO_2e/boe$ and are converted internally in the model to gCO_2e/MJ using the formula given in Equation 03.

The combined upstream emissions from Shell and non-Shell oil from country cu are now calculated internally in the model as follows:

$$CI_{cu,t}^{pr} = CI_{cu,t}^{pr,s} * min\left[1, \frac{P_{cu,t}^{s}}{C_{cu,t}}\right] + CI_{cu,t}^{pr,\bar{s}} * (1 - min\left[1, \frac{P_{cu,t}^{s}}{C_{cu,t}}\right]) \qquad \text{(Eq. 06)}$$

where $P_{cu,t}^{s}$ is the oil produced by Shell (s) assets in country cu and $C_{cu,t}$ is the oil that is used by all Shell refineries that originates from country cu. The units of P and C are boe/day. $P_{cu,t}^{s}$ is calculated internally in the model from the production of each oil producing asset. $C_{cu,t}$ is calculated internally in the model based on the total crude processed by each refinery and the diet (breakdown of crude sources by country). We note the following for Equation 06:

- Shell may be producing oil in certain countries but none of the Shell refineries uses this oil. In this case, $CI_{cu,t}^{pr}$ is not computed.
- There may be countries where Shell produces more oil than required by all the refineries in Shell's portfolio. In this case the Shell refineries use all the oil produced by Shell's asset and any surplus is left unused.
  In this case $CI_{cu,t}^{pr,\bar{s}} * (1 - min\left[1, \frac{P_{cu,t}^{s}}{C_{cu,t}}\right])$ becomes zero.
- There may be cases where some Shell refineries use oil from country cu but Shell does not produce any oil in that country. In this case, $CI_{cu,t}^{pr,s} * min\left[1, \frac{P_{cu,t}^{s}}{C_{cu,t}}\right]$ becomes zero.
- There may be countries where Shell produces oil but the consumption of oil from this country by all refineries is greater than the production by Shell. In this case, the priority is set so that refineries first use the oil produced by Shell and the balance is provided by non-Shell assets. $CI_{cu,t}^{pr}$ in this case is a weighted average.

The upstream intensity for each refinery asset, Ar, $CI_{Ar,t}^{pr}$ is now calculated internally in the model as follows:

$$CI_{Ar,t}^{pr} = \sum_{cu} CI_{cu,t}^{pr} * W_{Ar,cu} \qquad \text{(Eq. 07)}$$

The units are gCO_2e/MJ. $W_{Ar,cu}$ is the fraction of oil from country cu that is used by refinery Ar, also known as refinery diet. We note that the upstream intensity is now refinery specific thus we use the notation $CI_{Ar,t}^{pr}$ instead of $CI_{Au,t}^{pr}$.

The intensity of exporting oil from all the countries cu to refinery Ar is CI_{Ar}^{exp}. This is calculated for each refinery on a weighted basis as follows

$$CI_{Ar}^{exp} = \sum_{cu} D_{Ar,cu}^{shp/pipe} * Ci^{shp/pipe} * W_{Ar,cu} \qquad \text{(Eq. 08)}$$

We again note that these emissions are refinery specific and thus we use the notation CI_{Ar}^{exp} instead of $CI_{cu,cr}^{exp}$. shp denotes shipping mode of transport and $pipe$ denotes pipeline mode of transporting oil to refinery Ar from country cu. The refinery emissions $CI_{Ar,t}^{ref}$ and distribution emissions CI^{dst} in Equation 01 and end-use emissions CI_{f}^{veh} in Equation 02 remain unchanged. The WtT emissions for refinery Ar are thus given as follows.

$$CI_{Ar,t}^{WtT} = CI_{Ar,t}^{pr} + CI_{Ar}^{exp} + CI_{Ar,t}^{ref} + CI^{dst} \quad \text{(Eq. 09)}$$

The WtT emissions for the portfolio of Shell's refinery assets are now simply the weighted average of all the refineries. In other words,

$$CI_{port,t}^{WtT} = \frac{\sum_{Ar} CI_{Ar,t}^{WtW} * P_{Ar,t}}{\sum_{Ar} P_{Ar,t}} \quad \text{(Eq. 10)}$$

Where $P_{Ar,t}$ is the amount of crude processed at refinery Ar at time t.

2.4.4. Portfolio CI of Oil Sales

The OIL Sales calculation is driven by a list of Shell sales by region, which sets out the final delivered energy. It is assumed that refinery products sold in the region are from Shell refineries with any shortfall topped up from 3rd party refineries.

$$P_{Rg,t}^{sale} = P_{Rg,t}^{non-Shell} + P_{Rg,t}^{Shell} \quad \text{(Eq. 11)}$$

Where $P_{Rg,t}^{Shell} = \sum_{Ar}^{Rg} P_{Ar,t}^{Shell}$

The CI of oil product sales from Shell refineries is calculated as below:

$$CI_{Rg,t}^{WtT,Shell} = \frac{\sum_{Rg} CI_{t}^{WtT} * P_{Ar,t}^{Shell}}{\sum_{Rg} P_{Ar,t}^{Shell}} \quad \text{(Eq. 12)}$$

To calculate the WtT CI of sales from non-Shell refineries, the regional refinery diet is calculated first, assuming that it is the weighted average of Shell refineries in the sales region:

$$W_{Rg,cu} = \frac{\sum_{Ar} P_{Ar,t}^{Rg} * W_{Ar}^{Rg}}{\sum_{Ar} P_{Ar,t}^{Rg}} \quad \text{(Eq. 13)}$$

Crude production from upstream countries to supply the region is:

$$P_{(Rg,cu)t}^{non-Shell} = Eff_{(Rg,Ar)} * P_{(Rg,Ar)t}^{non-Shell} \quad \text{(Eq. 14)}$$

Where $Eff_{(Rg,Ar)}$ is the weighted average refinery efficiency in the region calculated based on Shell refinery production and efficiency.

The upstream CI for non-Shell refineries in the region is:

$$CI_{(Rg,cu)t} = \frac{\sum_{cu} CI_{cu} * P_{(Rg,cu)t}^{non-Shell} * W_{Rg,cu}}{\sum_{Rg} P_{(Rg,cu)t}^{non-Shell} * W_{Rg,cu}} \quad \text{(Eq. 15)}$$

The non-Shell crude is refined at an intensity equal to the average intensity of Shell refineries in the sales region:

$$CI_{(Rg,Ar)\,t}^{Shell} = \frac{\sum_{Rg} CI_{Ar,t}^{ref} * P_{Ar,t}}{\sum_{Rg} P_{Ar,t}} \quad \text{(Eq. 16)}$$

The WtT CI of sales from non-Shell refineries in each region are:

$$CI_{Rg,t}^{WtT,non-Shell} = CI_{(Rg,cu)t} + CI_{Rg,t}^{exp} + Eff_{(Rg,Ar)} * CI_{(Rg,Ar)\,t}^{Shell} + CI^{dst} \quad \text{(Eq. 17)}$$

Where $CI_{Rg,t}^{exp}$ is the weighted average shipping distance from crude producing country to the representative country in the sale regions (Europe=Netherlands, Asia-Pacific=China, America=United States, Africa=South Africa, Oceania = New Zealand).

For regions where there are no Shell refineries i.e. Oceania, a global refinery CI is used in Eq.17.

The WtT emissions for Shell's sales oil portfolio is now simply the weighted average of all the regions:

$$CI_{Port,t}^{WtT} = \frac{\sum_{Rg,t} CI_{Rg,t}^{WtT,Shell} * P_{Rg,t}^{Shell} + CI_{Rg,t}^{WtT,non-Shell} * P_{Rg,t}^{non-Shell}}{P_{Rg,t}^{sale}} \quad \text{(Eq. 18)}$$

The WtW CI of the oil portfolio processed calculation is the sum of $CI_{Port,t}^{WtT}$ and CI of the end-use.

3. Gas Portfolio

3.1. The structure of the gas portfolio calculation

Like the OIL portfolio, natural gas is produced in many different countries. In maritime locations, gas is often exported in the form of liquefied natural gas (See Chapter 4, LNG). In continental locations, gas is usually transported by pipeline. The GAS portfolio consists of those assets supplying end-users with pipeline gas.

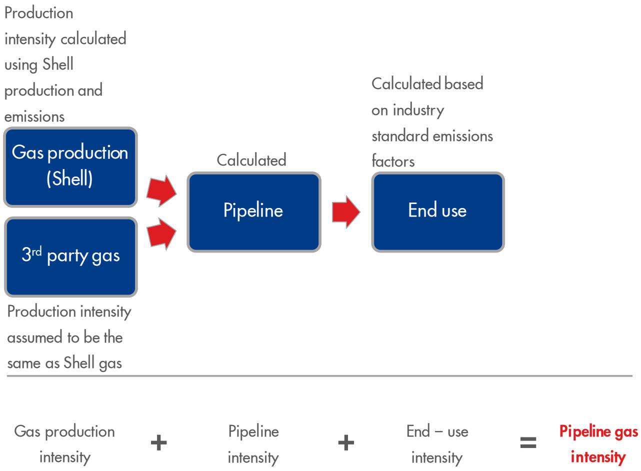

Figure 8 – Pipeline gas supply chain

Figure 8 shows an overview of the NG supply chain.

The NCF calculation works through a list of Shell gas production assets, described by:

- Gas production intensity by year (in $kgCO_2e$/boe)
- Gas production volume by year (in bsm^3/year)
- The pipeline distance (in km).

It is also necessary to know the intensity of non-Shell gas production:

- Gas production intensity by year (in $kgCO_2e$/boe) by country

The lifecycle calculation is completed with the following parameters:

- End-use intensity of natural gas combustion (in gCO_2e/MJ of gas)

3.2. Input data for GAS portfolio calculation

Data for gas producing assets in terms of CI and production rates are from taken from Shell's business reporting data. Both oil and gas assets produce gas or associated gas. Therefore, CIs of oil and gas assets are expressed as $kgCO_2e$/boe which are then converted to gCO_2e/MJ of total hydrocarbons. It means the emissions are allocated between oil and associated gas (or condensate and gas) on a hydrocarbon energy content basis for those assets which produce both.

The pipeline length in the calculation is defined for each country as detailed in APPENDIX 3. Pipeline emission factors [8] are then applied to the pipeline distance to calculate emissions from the pipeline transfer of gas, 3.22 gCO_2e/MJ/1000km, and the loss factor, 0.0148 MJ/MJ/1000km.

Power plants are assumed to be the end-use of natural gas. The functional unit of the analysis is MJ of energy supplied, so the efficiency of the end-use is immaterial. Most of the emissions from power plants or boilers result from conversion of the carbon content of the fuel to CO_2 together with methane emissions (unburned fuel) and N_2O emissions associated with combustion. The carbon intensity of end-use is taken to be 56.55 gCO_2e/MJ, the emissions factor of natural gas combustion from a NETL report on U.S. natural gas power generation [28].

Shell also sells gas produced by 3rd parties, these volumes have not been historically disclosed but will be disclosed as a single figure for global 3rd party gas sales in Shell's Sustainability Report beginning in 2019. These volumes are included in the NCF.

3.3. The methodology for the GAS Portfolio

3.3.1. Gas Balance – allocation of gas production to pipeline, LNG, GTL and power

Because natural gas from oil and gas assets can be sold as pipeline gas or used as feed gas for LNG, GTL or power plants, a rule is applied to separate them.

If there are LNG, GTL or power plants in a given country, any upstream gas assets in that country are assumed to provide feed gas to those assets. If there is insufficient gas to satisfy all in-country plants, the available Shell gas is distributed pro-rata with the plants' feed gas demand. If there is excess production, then the surplus will be routed to pipeline gas or LNG, as appropriate to each country. (There are no 3rd-party GTL plants receiving Shell gas production).

Four WtW pathways are needed to describe the transport of natural gas from production to end-user:

- GAS shows gas transported by pipeline
- LNG shows gas transported in the form of LNG and regasified
- GTL shows gas transformed into liquid fuel
- ELEC shows gas transformed into electricity

The NCF Model automatically distributes gas production from Shell assets to one of these four pathways. The "fate of gas" is tracked in the model and it can be demonstrated that the total gas production is equal to the total gas received by pipeline, LNG, GTL and power plants.

The model is also able to link gas production assets dedicated to particular liquefaction assets, which gives a truer picture of each plant's intensity rather than using a country-average feed gas intensity for all plants. However, for the NCF calculation, country averages suffice.

The first step is to calculate total gas production by country, and the total gas demand of Shell LNG and GTL plants in each country, as shown below

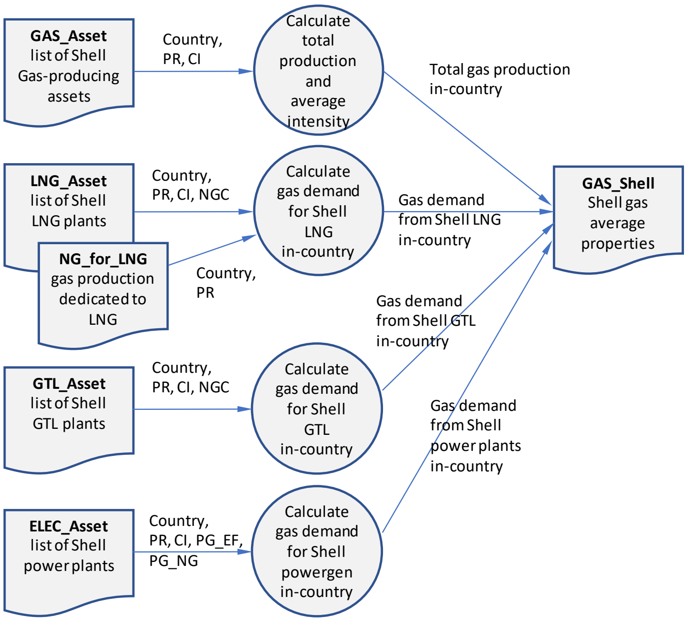

Figure 9 – Gas Balance calculation

- A list of unique country names is built from the list of gas, LNG, GTL and power plants.
- The total Shell gas production and intensity by country is calculated from the list of gas producing assets.
- The total gas demand from Shell LNG plants in each country is calculated from the production and efficiency for all LNG plants. (It is not necessary to count the gas demand of integrated plants because these assets are already bundled with their own gas supply.)
- Total gas demand from Shell GTL plants in each country is calculated from production and efficiency for all GTL plants.
- Likewise, total gas demand from Shell power plants in each country is calculated from production, efficiency, and natural gas fuel fraction for all power plants.

3.3.2. Gas Production calculation

The purpose of the Gas Production calculation is to calculate the WtW intensity of all Shell-produced gas that reaches the end-user in the form of pipeline gas. The well-to-wheel pathway is completed with transport via a generic (non-Shell) pipeline and end-use at a power plant.

The Gas Production calculation is driven by the list of gas producing assets. The final energy delivered to the end-user corresponds to the amount of Shell gas production that is allocated to pipeline (excluding gas used for Shell LNG, GTL and power generation) after allowing for losses in pipeline transmission.

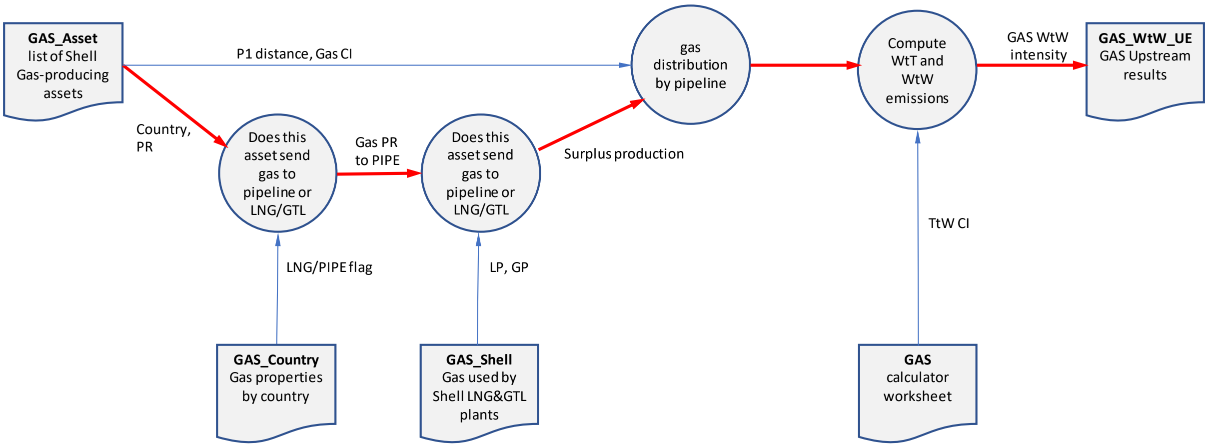

Figure 10 - GAS Production data flow diagram

- For each asset, we see if the country is listed as an LNG exporter. If it is, then no gas goes to pipeline.
- If the country is not an LNG exporter, then we consult the Gas Balance to see if there is any surplus gas after in-country Shell LNG, GTL and power plants have been supplied. If no gas remains, then no gas goes to pipeline.
- If there is surplus gas, then a fraction of each asset's gas is reserved for Shell LNG and GTL plants and the remainder is sent to pipeline.
- For each gas source, the pipeline distance is looked up and the transport emissions calculated.
- The WtW pathway is completed with end-use intensity.

The intensity used in the NCF calculation is then completed by analysing gas sales.

3.3.3. GAS Processed calculation

The Shell Processed view is taken to be the same as the Shell Production view. Unlike oil refining, Shell does not process non-Shell gas for sale as a Shell product.

3.3.4. Gas Sales calculation

The purpose of the Gas Production calculation is to calculate the WtW intensity of all gas sold by Shell that reaches the end-user in the form of pipeline gas. The volume captures Shell-produced pipeline gas and 3rd party gas which is sold by Shell.

3.4. Implementation of the calculation methodology for the gas portfolio

3.4.1. Acronyms, abbreviations and variables

The list of core variables and notations used in the gas portfolio calculation are given in Table 2.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	Carbon intensity (gCO_2e/MJ)	12	$Port$	Portfolio
2	Pr	Production volume (bsm^3/y)	13	PD	Pipeline distance
3	NG	Natural gas	14	Ci	Carbon intensity in tCO_{2e}/t
4	GP	Gas production	15	LA	LNG asset
5	GC	Gas consumption as fuel	16	Sur	surplus
6	A	Asset	17	PG	Power generation
7	GL	Gas Loss	18	$Elec$	Electricity
9	C	Country	19	Eff	Power plant efficiency
10	t	Year t	20	Gf	Power plant gas fuel fraction
11	WtT	Well to tank			

Table 2 - Acronyms, abbreviations and variables used in the GAS calculation

3.4.2. Gas Balance calculation

The Gas Balance for a country is calculated as follows.

$Pr_{c,t}^{NG}$ is the total volume of gas produced in country c.

$$Pr_{c,t}^{NG} = \sum_A Pr_{A,t}^{NG} \qquad \text{(Eq. 19)}$$

At the same time, the country-average intensity of Shell gas production can be calculated.

$$CI_{c,t}^{NG} = \frac{\sum_A CI_{A,t}^{NG} \times Pr_{A,t}^{NG}}{\sum_A Pr_{A,t}^{NG}} \qquad \text{(Eq. 20)}$$

The total gas consumption of LNG plants in each country, $Pr_{c,t}^{NG\ for\ LNG}$ is calculated based on LNG production and the plant gas consumption in country c.

$Pr_{A,t}^{Dedicated\ NG\ for\ LNG}$ is gas production dedicated to specific LNG assets in country c or upstream gas for integrated LNG. This gas is not supplied by assets in the gas production list and therefore needs to be subtracted from the total gas required for LNG.

$$Pr_{c,t}^{NG\ for\ LNG} = \left(\sum_A Pr_{A,t}^{LNG} - \sum_A Pr_{A,t}^{Dedicated\ NG\ for\ LNG}\right) * \left(1 + GL_{LA,t}\right) \qquad \text{(Eq. 21)}$$

The total gas consumption of GTL plants in each country, $Pr_{c,t}^{NG\ for\ GTL}$ is calculated based on GTL production and the plant gas consumption in country c.

$$Pr_{c,t}^{NG\ for\ GTL} = \sum_A Pr_{A,t}^{GTL} * \left(1 + GL_{A,t}^{GTL}\right) \qquad \text{(Eq. 22)}$$

The total gas consumption of power plants in each country, $Pr_{c,t}^{NG\ for\ PG}$ is calculated based on electricity generation and power plant efficiency in country c.

$$Pr_{c,t}^{NG\ for\ PG} = \sum_A Pr_{A,t}^{Elec} * Gf_{A,t}^{elec} / Eff_{A,t}^{Elec} \qquad \text{(Eq. 23)}$$

It is then possible to determine whether there is any surplus gas in each country, after all Shell LNG, GTL and power plants have been supplied.

$$Pr_{c,t}^{NG\_Sur} = Pr_{c,t}^{NG} - Pr_{c,t}^{NG\ for\ LNG} - Pr_{c,t}^{NG\ for\ GTL} - Pr_{c,t}^{NG\ for\ PG} \quad \text{(Eq. 24)}$$

If $Pr_{c,t}^{NG\_Sur} > 0$ and country c is a pipeline country (see Section 3.3.1), then the WtW intensity of the surplus pipeline gas is calculated following Section 3.4.3 below.

3.4.3. Lifecycle CI calculation

For gas delivered as pipeline gas, the total CI is expressed in units of gCO_2e/MJ.

$$CI_{A,t}^{WtT} = CI_{A,t}^{NG} * \left(GC_{A,t}^{Pipeline} + 1\right) + CI_{A,t}^{Pipeline} \quad \text{(Eq. 25)}$$

$$CI_{A,t}^{WtW} = CI_{A,t}^{WtT} + CI_{PG} \quad \text{(Eq. 26)}$$

Because gas is consumed as fuel in pipeline transmission, the CI is calculated to capture the loss in the denominator of final energy.

Gas Production

For Asset A in year t, the total CI in gCO_2e/MJ for gas production is

$$CI_{A,t}^{NG} = CI_{A,t}^{Production} * 1000/LHV_{gas} \quad \text{(Eq. 27)}$$

where $CI_{A,t}^{Production}$ is the carbon intensity of gas production in $kgCO_2e/boe$ for Asset A at year t. LHV_{gas} is the lower heating value of gas in MJ/boe.

Pipeline

The pipeline distance PD is listed for each gas production asset. Gas consumption and CI of pipeline transfer are calculated using the equations below:

$$GC_{A,t}^{Pipeline} = PD * GC_{pipeline} \quad \text{(Eq. 28)}$$

$$CI_{A,t}^{Pipeline} = PD * CI^{Pipeline} \quad \text{(Eq. 29)}$$

$GC_{pipeline}$ is the gas consumption as t/t-km and $CI^{Pipeline}$ is the intensity in $gCO_2e/MJ.km$. The pipeline emissions factors were taken from the NETL Unit Process Library [8] and are assumed to be constant over time and geography.

End-use

Combustion at a power plant is assumed to be the end-use of natural gas. The emissions intensity is expressed as gCO_2e/MJ of gas burned.

3.4.4. Portfolio CI of gas – Production view

Using the CI and gas consumption combined with the corresponding pipeline distance, we get the WtT CI for each asset using Eq.30.

The overall CI for the gas portfolio in gCO_2e/MJ is

$$CI_{Port,t}^{WtT} = \frac{\sum_A CI_{A,t}^{WtT} * Pr_{A,t}}{\sum_A Pr_{A,t}} \quad \text{(Eq. 30)}$$

and the total production is

$$Pr_{Port,t} = \sum_A Pr_{A,t} \quad \text{(Eq. 31)}$$

The WtW CI of the gas portfolio is the sum of $CI_{Port,t}^{WtT}$ and the CI of the end-use.

3.4.5. Gas Sales

Gas sales volumes are additional to Shell production, which is netted out to avoid double-counting. The list of sales "assets" by country is listed separately from Shell gas production. The analysis of WtW intensity is identical to the gas production methodology, except that there is no need to consider the Gas Balance because all the gas is non-Shell production.

The WtT (well-to-end-use) intensity of gas purchased for sale must be determined. The country-average intensity of pipeline gas is used where this is known (e.g. GREET in the U.S. [4] or GaBi/JEC for Europe [7]).

The contribution of gas sales to the NCF is then the sum of Shell gas production and sales of non-Shell gas.

4. LNG Portfolio

4.1. The structure of the LNG portfolio calculation

Figure 11 shows an overview of the LNG supply chain.

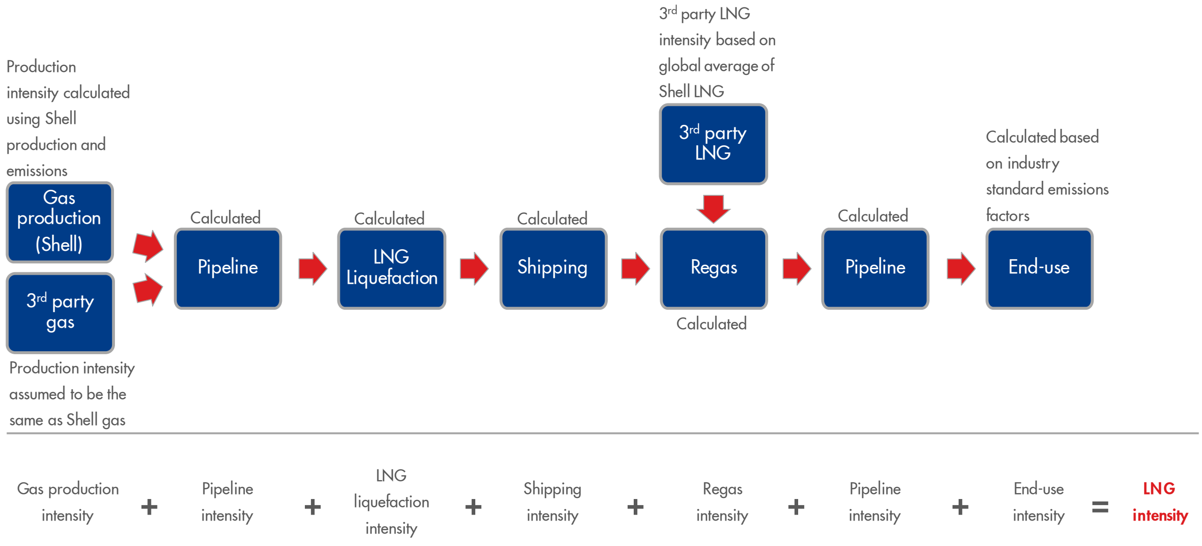

Figure 11 – The LNG supply chain

The NCF calculation works through a list of Shell LNG production assets, described by:

- LNG plant intensity (in $kgCO_2e/boe$) and gas consumption (in MJ_{NG}/MJ_{LNG})
- The supply gas pipeline distance (in km)

It is also necessary to know the intensity of Shell and non-Shell gas supplied to the LNG plants:

- Shell gas production intensity by year by country
- 3rd party gas production intensity by year by country

The life cycle is completed by:

- Shipping intensity and fuel use
- Regasification intensity and fuel use
- Distribution pipeline distance
- End-use (tank-to-wheel) intensity.

4.2. Input data for the LNG portfolio calculation

The emissions and production data for LNG assets are taken from Shell's business reporting data. Gas loss as fuel and as a result of impurity removal is either based on actual figures or Shell assumptions. For upstream, both oil and gas assets produce gas or associated gas as feedstock for LNG plants. Therefore, CIs of oil and gas assets are expressed as $kgCO_2e/boe$ which are then converted to gCO_2e/MJ of total hydrocarbons. It means the emissions are allocated between oil and associated gas (or condensate and gas) on a hydrocarbon energy content basis for those assets who produce both.

Pipeline transport of gas to the LNG plant uses the same emissions intensity and loss factors defined in Section 3.2.

When assessing Shell LNG liquefaction, we assume that all feed gas is taken at the average intensity of Shell gas producing assets located in the same country and any gap between Shell's production and the total feed gas requirement is filled with 3rd party gas with a country-average carbon intensity. There is no readily available source for the carbon intensity of 3rd party gas production, so non-Shell gas is assumed to have the same intensity as Shell gas. Where there are no Shell assets in-country, a world average intensity is used.

For LNG shipping, the shipping distance (SD) may be provided by Shell assets. For assets where this information is not available, an estimate is made based on an analysis of LNG trade volumes between countries by the International Gas Union [9] as described in Appendix 4 - a weighted sum of the shipping distance from the Shell LNG plant to each trade region and the corresponding fraction of production sent to each trade region. The emission factor for shipping is taken to be an average based on the fuel consumption and capacity of 24 Shell vessels, combined with IMO emissions factors for fuel combustion [10]. An estimate of methane slip is included in the GHG emissions, taken from a more recent SINTEF study in 2017 [11].

Emissions from regasification facilities are estimated based on a disclosure by Tokyo gas [12]. Gas loss as fuel is calculated to be 0.09% but including emissions from electricity consumption raises the intensity of regasification to 0.0173 tCO_2e/tLNG [13]. For gas pipelines from regasification terminals to end-user power plants, a proxy distance of 150 km was assumed.

As for pipeline gas, power plants are assumed to be the end-use of natural gas. The functional unit of the analysis is MJ of energy delivered, so the efficiency of the end-use is immaterial. Most of the emissions from power plants or boilers result from conversion of the carbon content of the fuel to CO_2 together with methane emissions (unburned fuel) and N_2O emissions associated with combustion. The carbon intensity of end-use is taken to be taken to be 56.55 gCO_2e/MJ, the emissions factor of natural gas combustion from a NETL report on U.S. natural gas power generation [28].

4.3. The methodology for the LNG Portfolio

The WtT and WtW emissions are estimated across the entire value chain using two perspectives – the Shell Processed and the Shell Sales calculation.

Similar to the Oil Processed portfolio, Shell LNG plants are preferentially supplied with Shell gas and any shortfall is made up with 3rd party gas. Unlike refineries, which take crude supplied from many countries, LNG plants are assumed to be supplied with gas from the country in which they are situated.

The availability of Shell gas in-country and the share that can be allocated to LNG is calculated in the Gas Balance (Section 3.3.1).

4.3.1. LNG Processed calculation

The purpose of the LNG Processed calculation is to calculate the WtW intensity of all Shell-processed LNG. Building a well-to-wheel pathway for each Shell LNG plant may involve feed gas from Shell or non-Shell production.

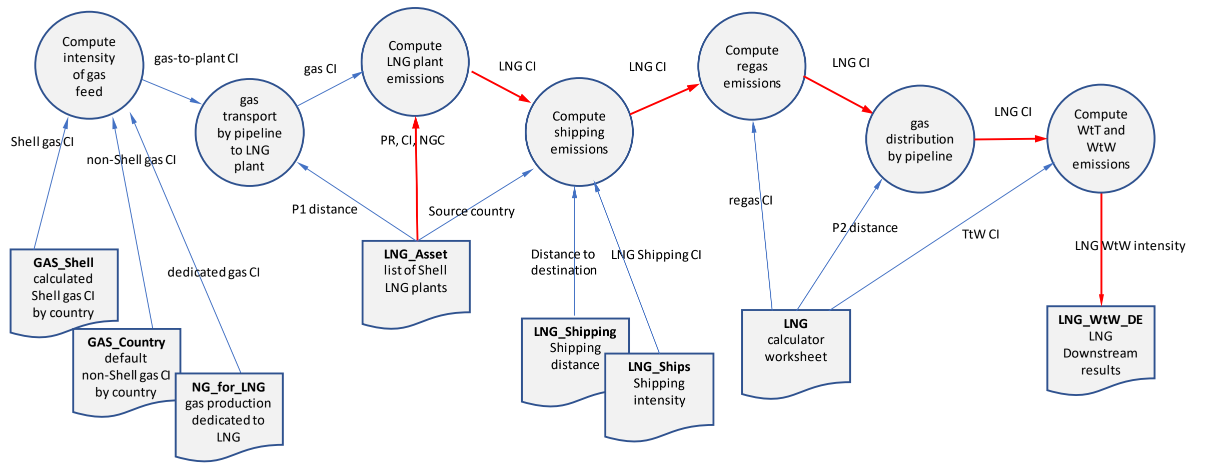

Figure 12 - LNG Processed data flow diagram

- For each Shell LNG plant, we determine the amount of feed gas needed for LNG production and the plant's gas consumption per unit produced.
- First, we consider dedicated feed gas assets. There may be more than one feed source. The total production and average intensity are calculated. Total dedicated production may not be enough to satisfy all the gas processed by the LNG plant.
- If there is a shortfall in feed gas, we next look to country-average Shell gas production to fill the gap. This intensity was calculated on a country-average basis in the Gas Balance. Total Shell production may not be enough to satisfy all the gas processed by the LNG plant.
- If there is still a shortfall in feed gas, we next look to country-average non-Shell gas production to fill the gap.
- A composite gas production intensity is calculated as a weighted average of all three gas sources.
- The intensity of transporting gas to the plant is calculated from the pipeline distance.
- Shipping distances are looked up for the region or country where the LNG plant is located.
- The WtW pathway is completed with regas, pipeline distribution and end-use intensities.

4.3.2. LNG Sales calculation

At present, LNG sales are analysed as a single global region. In future, it may be possible to provide a regional breakdown, as for sales of oil products.

The assumption is that non-Shell LNG is produced at the same intensity as world-average Shell LNG. The contribution of LNG Sales has the same intensity as Shell Processed LNG. The contribution to the portfolio footprint is in direct proportion to the final energy delivered – slightly smaller than the sales volume ex-ship after allowing for regas and pipeline distribution.

4.4. Implementation of the calculation methodology for the LNG portfolio

4.4.1. Acronyms, abbreviations and variables

The list of core variables and notations used in the LNG portfolio are given in Table 3.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	Carbon intensity in gCO_2e/MJ	10	C	Country
2	Pr	Production	11	SR	Shipping region
3	NG	Natural gas	12	t	Year
4	GP	Gas production for LNG	13	WtT	Well to Tank
5	LNG	Liquified natural gas	14	P	Portfolio
6	GL	Gas Loss	15	PD	Pipeline distance
7	GC	Gas Consumption as fuel use	16	$WtLA$	Well to loading arm
8	A	Gas Asset	17	$sale$	Sales mass
9	LA	LNG Asset	18	PG	Power generation

Table 3 - Acronyms, abbreviations and variables used in the LNG calculation

4.4.2. Lifecycle CI calculation

For gas delivered as LNG, the total CI is expressed in units of gCO_2e/MJ.

$$CI_{(A,LA),t}^{WtT} = \{[CI_{LA,t}^{WtLA} * (1 + GC_{LA,t}^{Shipping}) + CI_{LA,t}^{Shipping}] * (GC_{regas\ plant} + 1) + CI_{re-gas\ plant}\} * (1 + GC_{LA,t}^{Pipeline\_PL}) + CI_{LA,t}^{Pipeline\_PL} \quad \text{(Eq. 32)}$$

$$CI_{(A,LA),t}^{WtLA} = [CI_{t}^{NG} * (1 + GC_{pipeline}) + CI^{Pipeline}]*(1+GL_{LA}) + CI_{LA,t}^{LNG} \quad \text{(Eq. 33)}$$

$$CI_{(A,LA),t}^{WtW} = CI_{(A,LA),t}^{WtT} + CI_{PG} \quad \text{(Eq. 34)}$$

Because gas is consumed as fuel in pipeline transport, LNG production, shipping, regasification and distribution, the CI is calculated to capture the loss in the denominator of final energy.

Gas Production

The country-average Shell gas production $CI_{C,t}^{NG}$ is taken from the Gas Balance calculation (Section 3.4.2).

Pipeline to LNG

The pipeline distance, PD, for each LNG asset (LA) is listed for each Shell LNG plant. Using the appropriate pipeline distance, we can get the total CI up to the point at which gas is delivered to the LNG plant via the pipeline:

$$GC_{LA,t}^{Pipeline} = PD * GC_{pipeline} \quad \text{(Eq. 35)}$$

$$CI_{LA,t}^{Pipeline} = PD * CI^{Pipeline} \quad \text{(Eq. 36)}$$

$GC_{pipeline}$ is the gas consumption as t/t-km and $CI^{Pipeline}$ is the intensity in $gCO_2e/MJ/km$. The pipeline emissions factors were taken from the NETL Unit Process Library [8] and are assumed to be constant over time and geography.

LNG Production

For Asset LA in year t, the CI in gCO_2e/MJ for LNG production is

$$CI_{LA,t}^{LNG} = CI_{LA,t}^{Production} * 1000/LHV_{gas} \quad \text{(Eq. 37)}$$

GL_{LA} is the gas loss as fuel in LNG plant as MJ_{NG}/MJ_{LNG} and is listed for each Shell LNG asset.

Shipping

The shipping distance (SD) is based on a weighted sum of the shipping distance from the Shell LNG plant to each trade region and the corresponding fraction of production sent to each trade region.

$$SD_{LA} = SD_{A \in Export\ Country} = \sum_{Region\ i} SD_i * (Shipping\ Ratio)_i \qquad \text{(Eq. 38)}$$

Applying the GC and CI for shipping laden and shipping ballast gives:

$$GC_{LA}^{Shipping} = GC_{LA}^{Shipping\ laden} + GC_{LA}^{Shipping\ ballast} \qquad \text{(Eq. 39)}$$

$$CI_{LA}^{Shipping} = CI_{LA}^{Shipping\ laden} + CI_{LA}^{Shipping\ ballast} \qquad \text{(Eq. 40)}$$

Re-gasification

The constants $GC_{regas\ plant}$ and $CI_{regas\ plant}$ allow for fuel consumption and emissions of re-gasification of LNG.

Pipeline to power plant

Given the pipeline distance to the power plant, PD_{plant}, the gas consumption $GC_{LA,t}^{Pipeline\_PL}$ and $CI_{LA,t}^{Pipeline\_PL}$ are calculated as follows:

$$GC_{LA,t}^{Pipeline\_PL} = PD_{plant} * GC_{pipeline} \qquad \text{(Eq. 41)}$$

$$CI_{LA,t}^{Pipeline\_PL} = PD_{plant} * CI^{Pipeline} \qquad \text{(Eq. 42)}$$

End-use

Combustion at a power plant is assumed to be the end-use of LNG. The emissions intensity is expressed as gCO_2e/MJ of gas burned.

The final energy, used to calculate the weighting for the LNG supply chain in the NCF portfolio average, is the amount of gas delivered to the end-user – smaller than the amount of LNG produced by Shell as a result of gas used as fuel in shipping and pipeline transmission.

4.4.3. Portfolio CI of LNG – Processed view

The Processed calculation is driven by the LNG facilities gas demand: NG is processed in local LNG facilities from dedicated gas (if any) and LNG's share of Shell gas production, as calculated in the Gas Balance. Any shortfall is made-up from imports drawn from 3rd party production at country-average intensity for non-Shell gas.

First the gas required for LNG assets is calculated:

$$Pr_{LA,t}^{NG} = Pr_{LA,t}^{LNG} * \left(1 + GL_{LA,t}\right) * \left(1 + GC_{LA,t}^{Pipeline}\right) \qquad \text{(Eq. 43)}$$

Then the average production CI for gas supplied to LNG asset LA and the total gas production by dedicated gas assets (including those upstream of integrated gas assets) is:

$$CI_{LA,t}^{dedicated\ gas\_for\_LNG} = \frac{\sum_A CI_{A,t}^{dedicated\ gas\_for\_LNG} * Pr_{A,t}^{dedicated\ gas\_for\_LNG}}{\sum_A Pr_{A,t}^{dedicated\ gas\_for\_LNG}} \qquad \text{(Eq. 44)}$$

$$Pr_{LA,t}^{dedicated\ gas\_for\_LNG} = \sum_A Pr_{A,t}^{dedicated\ gas\_for\_LNG} \qquad \text{(Eq. 45)}$$

If $Pr_{LA,t}^{dedicated\ gas\_for\_LNG} > Pr_{LA,t}^{NG}$, it means dedicated gas is sufficient to supply the LNG asset and any surplus is ignored. The WtT CI calculation follows Eq. 32-33 where CI_t^{NG} is replaced by $CI_{LA,t}^{dedicated\ gas\_for\_LNG}$.

If $Pr_{LA,t}^{dedicated\ gas\_for\_LNG} < Pr_{LA,t}^{NG}$, it means dedicated gas is not sufficient to supply the LNG asset and the shortfall in gas is taken from the LNG country *C* with a CI taken from the Gas Balance calculation (Section 3.4.2). The total gas production in LNG country C is $Pr_{C,t}^{NG}$ in the Gas Balance.

If $Pr_{LA,t}^{dedicated\ gas\_for\_LNG} + Pr_{C,t}^{NG} > Pr_{LA,t}^{NG}$, it means Shell produced gas is sufficient to supply the LNG asset and there is no need for non-Shell gas.

The WtT CI calculation follows Eq. 32-33 where CI_t^{NG} is replaced by $CI_{LA,t}^{Shell\ NG}$.

$$CI_{LA,t}^{Shell\ NG} = \frac{\sum_A CI_{A,t}^{dedicated\ gas\_for\_LNG} * Pr_{A,t}^{dedicated\ gas\_for\_LNG} + CI_{C,t}^{NG} * (Pr_{LA,t}^{NG} - Pr_{A,t}^{dedicated\ gas\_for\_LNG})}{Pr_{LA,t}^{NG}}$$

(Eq. 46)

If $Pr_{LA,t}^{dedicated\ gas\_for\_LNG} + Pr_{C,t}^{NG} < Pr_{LA,t}^{NG}$, it means that non-Shell gas is required to fill the gap at an intensity of $CI_{c,t}^{non-Shell\ NG}$

$$CI_{LA,t}^{non-Shell\ NG} = \frac{\sum_A CI_{A,t}^{i} * Pr_{A,t}^{i} + CI_{C,t}^{NG} * Pr_{C,t}^{NG} + CI_{c,t}^{NG} * (Pr_{LA,t}^{NG} - Pr_{A,t}^{i} - Pr_{C,t}^{NG})}{Pr_{LA,t}^{NG}} \quad \text{(Eq. 47)}$$

Where *i*= $dedicated\ gas\_for\_LNG$. The WtT CI calculation follows Eq. 32-33 where CI_t^{NG} is replaced by $CI_{LA,t}^{non-Shell\ NG}$.

The portfolio WtT CI is:

$$CI_{Port,t}^{WtT} = \frac{\sum_{LA} CI_{LA,t}^{WtT,i} * Pr_{LA,t}^{LNG}}{\sum_{LA} Pr_{LA,t}^{LNG}} \quad \text{(Eq. 48)}$$

Where *i*= $dedicated\ gas\_for\_LNG$, $Shell\ NG$ and $non\_Shell\ NG$.

The WtW CI of the gas portfolio is the sum of $CI_{Port,t}^{WtT}$ and the CI of the end-use.

4.4.4. Portfolio CI of LNG sales

At present, LNG sales are analysed as a single global region. The assumption is that non-Shell LNG is produced at the same intensity as world-average Shell LNG. Therefore, the portfolio CI is the same as that of the LNG processed portfolio.

The quantity of LNG sold is the mass ex-ship. The final energy delivered to the end-user, used to calculate the weighting of the LNG supply chain in the NCF portfolio average, is reduced by fuel use in re-gas and pipeline transportation:

$$PR_{sale,t}^{WtT} = PR_{sale,t}^{WtT} / \left(GC_{regas\ plant} + 1\right) / (1 + GC_{Pipeline}) \quad \text{(Eq. 49)}$$

5. GTL Portfolio

Shell gas-to-liquids (GTL) technology converts natural gas to liquid fuels, chemicals and waxes. GTL is an alternative application for natural gas and Shell GTL plants exist alongside LNG plants in Qatar and Malaysia.

5.1. The structure of the GTL portfolio calculation

Figure 13 shows an overview of the LNG supply chain.

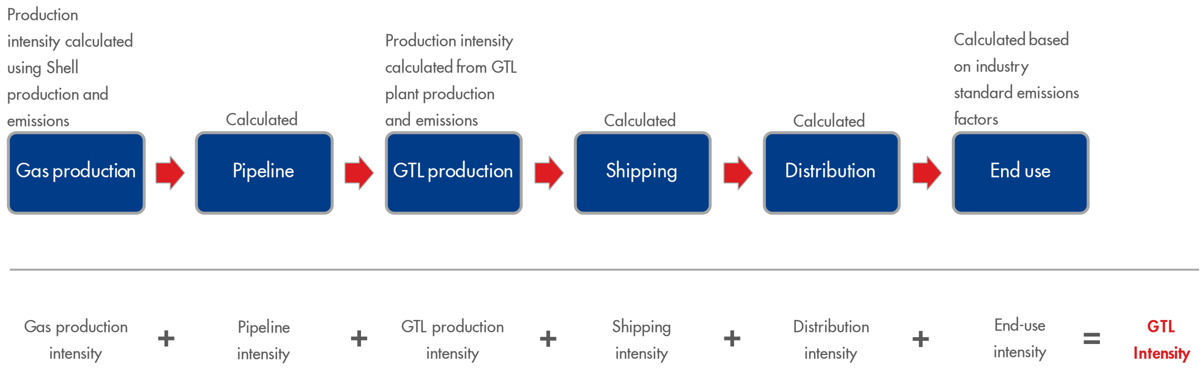

Figure 13 – The GTL supply chain

The NCF calculation works through a list of Shell GTL production assets, described by:

- GTL plant intensity (in $kgCO_2e$/boe) and gas consumption (in MJ_{NG}/MJ_{LNG})
- The supply gas pipeline distance (in km)

It is also necessary to know the intensity of Shell and non-Shell gas supplied to the GTL plants:

- Shell gas production intensity by year by country
- 3rd party gas production intensity by year by country

The life cycle is completed by:

- Shipping intensity
- Distribution to point-of-sale
- End-use (tank-to-wheel) intensity.

5.2. Input data for GTL portfolio

CI and production rate data for Shell's two GTL assets are taken from Shell business reporting data. Not all GTL products are energy products. To align with the scope of NCF, approximately 55% of Pearl GTL products [14] and 20% of SMDS GTL products [15] are included in the NCF calculation.

The CI of upstream gas production for SMDS is a country average over the lifetime of the GTL plant. Gas consumption as MJ_{NG}/MJ_{GTL} is estimated based on the reported plant thermal efficiency. A pipeline distance of 200 km was agreed with the project team.

Pearl GTL is an integrated gas asset; emissions of upstream gas production and pipeline transport are included in the asset's CI, and therefore their intensity is set to be zero to avoid double counting.

Pipeline transport of gas to the GTL plant uses the same emissions intensity and loss factors defined in Section 3.2.

The shipping distance for Pearl is set as a constant representing that from Qatar to Rotterdam; for Bintulu, from Bintulu to Osaka, Japan. A shipping emissions factor is derived from the GREET 2018 model for a GTL ocean tanker, 0.23 gCO_2e/MJ/1000km [4].

The CI of GTL distribution from import terminal to point of sale is a constant 0.63 gCO2e/MJ, derived from a JEC study [7].

The end-use of GTL is dependent on the portfolio of the GTL facility, however for reasons of simplicity, the end-use of GTL in this calculation model is assumed to be as a fuel for transport. GTL fuels have a lower carbon fraction than conventional oil-derived fuels and its combustion emissions factor is extracted from the same JEC study [7], 71.98 gCO_2e/MJ.

5.3. The methodology for the GTL Portfolio

5.3.1. GTL Processed calculation

The purpose of the GTL Processed calculation is to calculate the WtW intensity of all Shell-processed GTL. Building a well-to-wheel pathway for each Shell GTL plant may involve feed gas from Shell or non-Shell production.

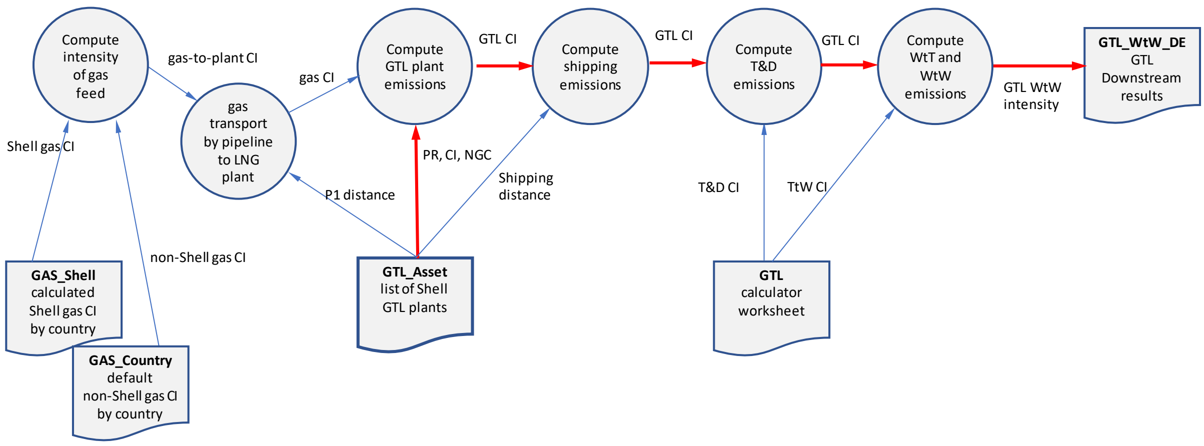

Figure 14 - GTL Processed data flow diagram

- For each Shell GTL plant, we determine the amount of gas feed needed based on the plants production and gas consumption.
- First, we look to country-average Shell gas production to supply the plant. The intensity is taken from the Gas Balance. Total Shell production may not be enough to satisfy all the gas processed by the GTL plant.
- If there is a shortfall in feed gas, we next look to country-average non-Shell gas production to fill the gap.
- A composite gas production intensity is calculated as a weighted average of both gas sources.
- The intensity of transporting gas to the plant is calculated from the pipeline distance listed for each GTL plant.
- The intensity of shipping GTL from the plant is calculated from the shipping distance listed for each GTL plant.
- The WtW pathway is completed with distribution and end-use intensities.

5.3.2. GTL Sales calculation

At present, it is assumed that GTL sales are equivalent to Shell's GTL production.

5.4. Implementation of the calculation methodology for the GTL Portfolio

5.4.1. Acronyms, abbreviations and variables

The list of core acronyms and abbreviations used by the GTL portfolio calculation are given in Table 4.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	Carbon intensity in units of CO_2e/MJ	11	LHV	Lower Heating Value
2	A	Asset	12	SD	Shipping distance
3	t	time	13	PD	Pipeline distance
4	Pr	Production	14	veh	Vehicle
5	p	Pipeline distribution	15	shp	Shipping
6	GtL	Gas to liquid	16	$Port$	Portfolio
7	dst	Distribution	17	pd	Pipeline distance
8	Ci	Carbon intensity in $kgCO_2e/boe$	18	GC	Gas consumption
9	WtT	Well to Tank	19	GL	Gas loss as fuel
10	WtW	Well to Wheel	20	Gp	Gas production

Table 4 - Acronyms, abbreviations and variables used in the GTL calculation

These core notations are used to derive variables used in the model and the report. For example, $CI_{A,t}^{GTL}$ would imply emissions for Asset A at time t (year) due to the process of converting gas to liquid. Similarly, $CI_{A,t}^{WtW}$ means Well to Wheel emissions for Asset A at time t, CI^{veh} indicates the emissions due to combustion of the GTL product in a car. We note that all the emissions are expressed in gCO_2e/MJ.

5.4.2. CI calculation

$$CI_{A,t}^{WtT} = [CI_{A,t}^{Gp} * (1 + GC_{pipeline}) + CI_{pipeline}] * (1 + GL_{GTL}) + CI_{A,t}^{GTL} + CI_{A}^{shp} + CI_{A}^{dst} \quad \text{(Eq. 50)}$$

$$CI_{A,t}^{WtW} = CI_{A,t}^{WtT} + CI^{veh} \quad \text{(Eq. 51)}$$

Because gas is consumed in pipeline and GTL plant, the CI is calculated cumulatively to capture the loss in the denominator of the CI.

Gas Production

The country-average Shell gas production $CI_{C,t}^{NG}$ is taken from the Gas Balance calculation (Section 3.4.2).

Pipeline to GTL

The pipeline distance, PD, is listed for each GTL asset. Using the appropriate pipeline distance, we can determine the total CI up to the point at which gas is delivered to the GTL plant via the pipeline:

$$GC_{GTL,t}^{Pipeline} = PD * GC_{pipeline} \quad \text{(Eq. 52)}$$

$$CI_{GTL,t}^{Pipeline} = PD * CI^{Pipeline} \quad \text{(Eq. 53)}$$

$GC_{pipeline}$ is the gas consumption as t/t-km. $CI^{Pipeline}$ is the intensity in gCO_2e/MJ.

GTL Production

For Asset GTL in year t, the CI in gCO_2e/MJ for GTL production is

$$CI_{GTL,t} = CI_{GTL,t}^{Production*} * 1000/LHV_{gas} \quad \text{(Eq. 54)}$$

GL_{GTL} is the gas loss as fuel in GTL plant as MJ_{NG}/MJ_{GTL}.

Shipping

The shipping distance (SD) is the shipping distance from GTL asset to destination country.

$$CI_{A}^{shp} = SD * CI_{GTL}^{shp} \quad \text{(Eq. 55)}$$

Where CI_{GTL}^{shp} is the GTL tanker emission factor.

Distribution and end-use

CI^{dst} is the intensity for distribution of the finished product, it is assumed to be a constant (that is, time and asset independent). CI^{veh} is the emissions factor of using GTL by road transportation vehicles (cars and trucks).

5.4.3. Portfolio CI of GTL - Processed view

For each Shell GTL plant, we determine the amount of gas feed needed $Pr_{GTL,t}^{NG}$

$$Pr_{GTL,t}^{NG} = (1 + GL_{GTL}) * Pr_{GTL,t} \quad \text{(Eq. 56)}$$

Then we go to the Gas Balance to see if there is any surplus gas after in-country LNG and power plants have been supplied:

$$Pr_{(A,Elec),t}^{NG\_Sur} = Pr_{c,t}^{NG} - (Pr_{c,t}^{NG\ for\ LNG} - \sum_A Pr_{A,t}^{Dedicated\ NG\ for\ LNG} + Pr_{c,t}^{NG\ for\ GTL} + Pr_{c,t}^{NG\ for\ Elec}) \quad \text{(Eq. 57)}$$

Where $Pr_{c,t}^{NG}$, $Pr_{c,t}^{NG\ for\ LNG}$, $Pr_{A,t}^{Dedicated\ NG\ for\ LNG}$ are described and calculated in Section 3.4.2.

If the surplus gas is not sufficient for the GTL plant ($Pr_{(A,GTL),t}^{NG\_Sur} < Pr_{GTL,t}^{NG}$), 3rd party gas is assumed to fill the gap.

$$CI_{(A,GTL),t}^{NG} = \frac{\sum_A CI_{A\in C,t}^{NG} * Pr_{(A,GTL),t}^{NG\_Sur} + CI_{C,t}^{NG} * (Pr_{GTL,t}^{NG} - Pr_{(A,GTL),t}^{NG\_Sur})}{Pr_{GTL,t}^{NG}} \quad \text{(Eq. 58)}$$

Then $CI_{(A,GTL),t}^{NG}$ replaces $CI_{A,t}^{Gp}$ in Eq. 50 for the WtT CI calculation.

The portfolio WtT CI at time t is:

$$CI_{Port,t}^{WtT} = \frac{\sum_{GTL} P_{GTL,t} * CI_{GTL,t}^{WtT}}{\sum_{GTL} P_{GTL,t}} \quad \text{(Eq. 59)}$$

The portfolio WtW CI is completed with CI^{veh}.

6. Biofuels

6.1. The structure of the Biofuels portfolio calculation

Biofuel production may choose to include or exclude land use change (LUC) emissions. The BIOFUEL supply chain excludes them because their inclusion might lead to changes in the NCF value as a result of legislated LUC intensities rather than by any action of Shell.

Figure 15 shows an overview of the Biofuel supply chain.

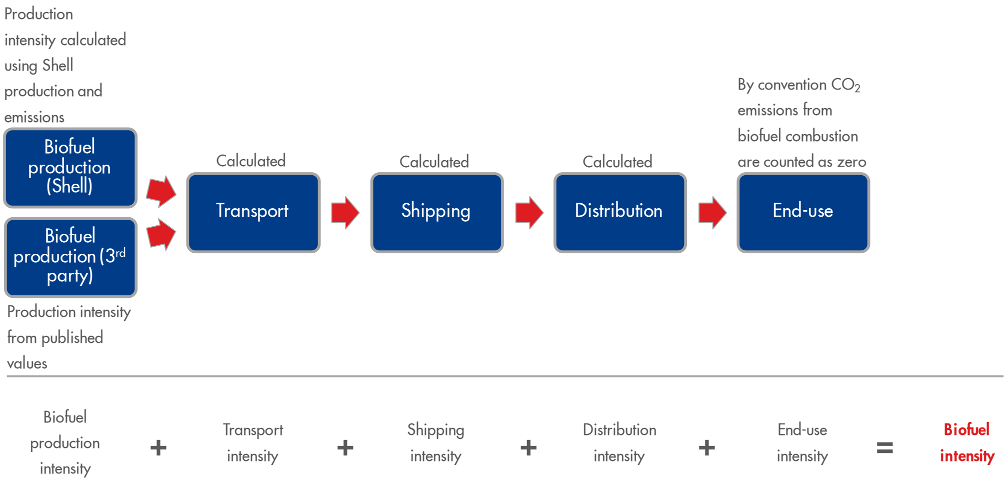

Figure 15 – The BIOFUEL supply chain

The NCF calculation works through a list of Shell biofuel production assets, described by:

- Production intensity (in $kgCO_2e/boe$)
- Product type: all fuels for spark ignition engines are treated as ethanol; all fuels for compression ignition engines are treated as FAME (there is, as yet, no significant volume of other biofuels in use).
- Feedstock type – may be used to lookup default intensities defined in regulations.

The life cycle is completed by:

- Transport intensity within the production region
- Shipping intensity between production and import region
- Distribution to point-of-sale
- End-use (tank-to-wheel) intensity.

6.2. Input data for BIOFUEL portfolio

The production rate for the Raízen 1st and 2nd generation plants are from the Shell Sustainability Report [16] whilst CIs (well-to-ethanol plant) are derived from EPA RFS2 2010 [17] and information obtained from Raízen's website [18].

The volume of biofuels purchased from 3rd party suppliers used in Shell's gasoline and diesel blends worldwide is from the Shell Sustainability Report. The disaggregation of this volume to different products, feedstock and regions uses data provided by Shell's New Energies business.

CIs of U.S. pathways are from EPA RFS2 and the CIs of European pathways are taken from the BioGrace model [19]. CIs and LUC factors of Canadian pathways are from GHGenius model

[29] and those of Eastern pathways are from various publications (cassava ethanol [20], molasses ethanol [21], coconut biodiesel [22] and palm oil biodiesel [23]). LUC emissions factors for U.S. biofuels are derived from EPA RFS2 whilst those for EU cases are taken from the EU iLUC Directive [24].

For simplicity of calculation, biofuels produced by a single asset are either consumed domestically or exported (assets may be split if they supply multiple destinations). For example, for Raízen, about 56% of biofuels are used domestically and 44% are exported to the U.S. based on information in the 2014/2015 Raízen Sustainability Report [25]. U.S. biofuels and EU biofuels are assumed to be consumed domestically. For export, biofuels are collected from plants by various methods e.g. truck, rail, barge and pipeline and transported to bulk terminals, and then shipped to the destination country via ocean tankers. A shipping matrix has been developed with distances from an online sea port calculation model [6] and emissions factors from the GREET model [4]. For domestic use, biofuels are also transported to bulk terminals and then distributed via truck.

For Tank-to-Wheel (TtW) CI, the transport sector is assumed to be the end-use of biofuels. The functional unit of the analysis is MJ of energy supplied, so the efficiency of the end-use is immaterial. Most of the end-use emissions result from conversion of the carbon content of the fuel to CO_2 together with methane emissions and N_2O emissions associated with combustion in engines. For biofuels, the carbon content of the fuel is not of fossil origin, so a "renewable combustion credit" is applied, reducing the emissions intensity to the methane and N2O elements alone. The intensity of distribution and end-use of biofuels are represented to be CI_A^{dst} and CI^{veh} which are constants from the JEC study [7]: 0.63 and 0.87 gCO_2e/MJ respectively.

6.3. The methodology for the BIOFUEL Portfolio

6.3.1. BIOFUEL Production calculation

The BIOFUEL Processed calculation is driven from a list of Shell biofuel production assets. The final energy delivered to the end-user is the same as the amount of Shell production because there are no processes that consume biofuel between production and end-use.

- For each Shell asset, the production and intensity of production is listed.
- Transport distances within a region, or shipping distances between regions are calculated.
- The WtW pathway is completed with distribution and end-use intensities.

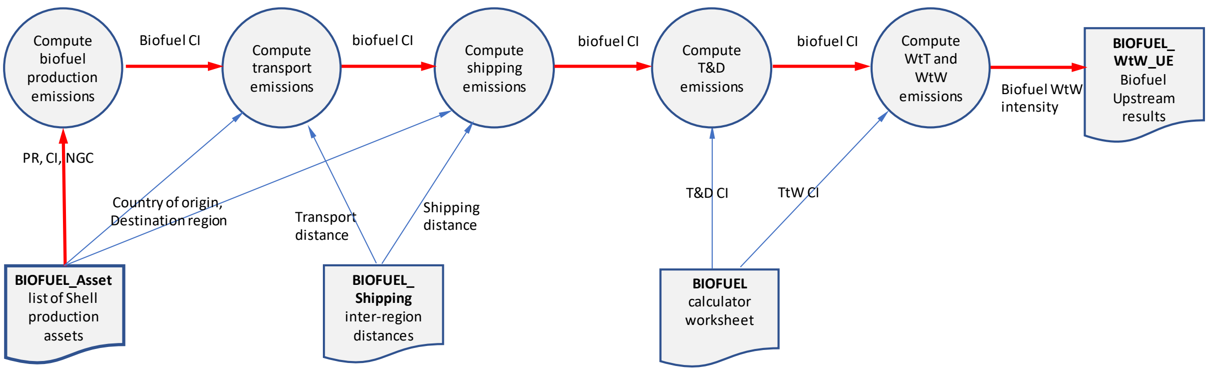

Figure 16 - BIOFUEL Production data flow diagram

6.3.2. BIOFUEL Processed calculation

The Shell Processed view is taken to be the same as the Shell Production view. Unlike oil refining, Shell does not process non-Shell biofuels for sale as Shell products.

6.3.3. BIOFUEL Sales calculation

Biofuels sales are increasing as a result of legislation that requires biofuels to be blended in transport fuels. Shell is a net seller of biofuels. Biofuel sales data is reduced from a large number of raw data records to total sales for Shell use organised by product, feedstock, region of production and region of sales.

- For each product, feedstock, and region of production, publicly-available production intensity values are looked up.
- Transport distances within a region, or shipping distances between regions are calculated.
- The WtW pathway is completed with distribution and end-use intensities.
- Lastly, the WtW emissions of Shell's own processing are added.

6.4. Implementation of the calculation methodology for the Biofuels portfolio

6.4.1. Acronyms, abbreviations and variables

The list of core variables and notations used in the LNG portfolio are given in Table 5.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	Carbon intensity in units of gCO_2e/MJ	8	WtT	Well to Tank
2	Pr	Production (in MJ)	9	WtW	Well to Whell
3	bio	Biofuel processing	10	$Port$	Portfolio
4	$tran$	Transport	11	t	Year t
5	shp	Shipping	12	A	Biofuel Asset
6	dst	Distribution	13	LUC	Land Use Change
7	veh	End-use in vehicle			

Table 5 - Acronyms, abbreviations and variables used in the BIOFUEL calculation

6.4.2. Portfolio CI of Biofuel - Production view

To implement the calculation, the following equations are used:

For Asset A in year t,

$$CI_{A,t}^{WtW} = (CI_{A,t}^{bio} + CI_{A}^{LUC}) + CI_{A}^{tran} + CI_{A,t}^{shp} + CI_{A}^{dst} + CI^{veh} \qquad \text{(Eq. 60)}$$

where $CI_{A,t}^{bio}$ is the well-to-product CI for biofuel processing which is listed for each biofuel asset, to which land use change emissions CI_{A}^{LUC} could be added if desired.

CI_{A}^{tran} is the CI of road transport and $CI_{A,t}^{shp}$ is the CI for shipping of biofuels.

Intensity of distribution and end-use of biofuels are represented as CI_A^{dst} and CI^{veh}. For the biofuels portfolio, the CI is then calculated by:

$$CI_{Port,t}^{WtW} = \frac{\sum_A P_{A,t} * CI_{A,t}^{WtW}}{\sum_A P_{A,t}} \qquad \text{(Eq. 61)}$$

where $P_{A,t}$ is the production rate of each biofuel production or sales asset.

7. SOLAR and WIND

SOLAR is essentially identical to WIND, so it is sufficient to describe only one of them here. They are treated separately to make the contribution of each individual supply chain to the NCF visible.

7.1. Fossil energy equivalent of electricity

WtW emissions for each pathway are calculated in the units of grams CO_2e per MJ of final energy delivered to the end-user: the energy content of gasoline at a filling station, the energy content of gas delivered to a power plant, or (in the case of solar and wind) one MJ of electricity. Fuel pathways should be compared or combined on the basis of equivalent functional units but this is difficult when the end products are dissimilar. The utility of one unit of electricity is higher than one unit of gas (because two units of gas must be burned to generate one unit of electricity) or gasoline (because three units of gasoline would be needed to cover the same distance in a vehicle as one unit of electricity in an electric vehicle). The portfolio is dominated by fossil energy and therefore it was decided to convert electricity to a notional fossil fuel equivalent to derive a portfolio average WtW intensity.

Using forecasts in IEA scenarios for world electricity generation and the corresponding fuel inputs (made up of a mix of energy sources: coal, oil, gas, nuclear and renewables) for each mode of generation, we can derive a time series for the ratio of electricity generated to the primary energy input. This ratio is expected to improve as the generation mix decarbonizes, and more renewable generation comes into the mix. For example, currently, at a ratio of 0.40, one unit of electricity is considered functionally equivalent to 2.5 units of input energy for power generation. The NCF model chooses to use the IEA's energy scenarios, which forecast an increasing contribution from renewables supported by efficient power generation and a decreasing role for coal.

7.2. Structure of the SOLAR and WIND portfolio calculation

Figure 17 shows how solar and wind fit into the electricity supply chain.

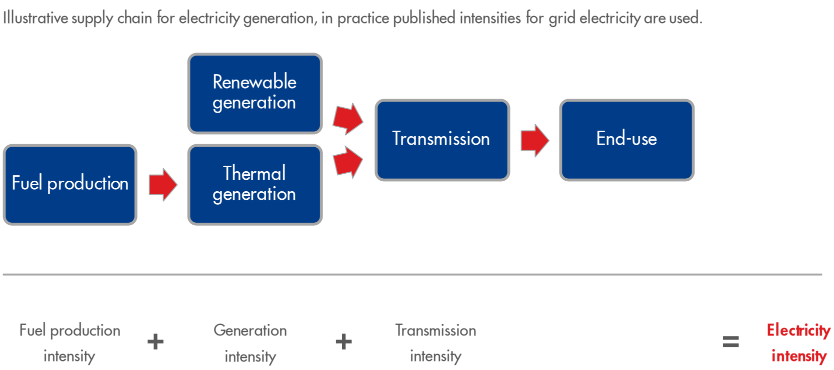

Figure 17 -SOLAR and WIND form the Renewable part of the ELECTRICITY supply chain

The NCF calculation works through a list of Shell SOLAR/WIND production assets, described by:

- Power generation intensity (generally zero for renewables).
- Total power generated

The life cycle is completed by:

- Conversion of final energy in MJ of electricity to MJ of fossil energy equivalent.
- No account is taken of distribution losses on the grid.

7.3. SOLAR and WIND input data

Shell has several onshore wind projects in the U.S. and one offshore wind installation in the Netherlands [16]. The CI of wind electricity is assumed to be 1gm $CO_{2\ eq}$/kWh from operations [39], excluding GHG emissions from plant construction, in alignment with the boundary definition for fossil fuel assets. Where the electricity production is unknown, this is estimated from nameplate capacity using country or regional average capacity factors specific to offshore and onshore wind technologies [26].

Although Shell currently has no large-scale solar PV assets, the inclusion of solar electricity in the portfolio calculation is a placeholder for future expansion. The CI of solar electricity is assumed to be 10gm $CO_{2\ eq}$/ kWh from operations [40], excluding GHG emissions from plant construction, aligning with the boundary definition for fossil fuel assets. Where the electricity production is unknown, this is estimated from nameplate capacity using country or regional average capacity factors for solar [26].

7.4. The methodology for the SOLAR and WIND Portfolio

7.4.1. SOLAR and WIND Production calculation

The SOLAR/WIND Production calculation is driven from a list of generating assets.

The methodology is a subset of the ELECTRICITY supply chain, which is described in the following chapter (ELEC, Section 8.4).

7.4.2. SOLAR and WIND Processed calculation

The Shell Processed view is taken to be the same as the Shell Production view. There is no processing of renewable energy after generation.

7.4.3. SOLAR and WIND Sales calculation

SOLAR/WIND sales are assumed to be the same as SOLAR/WIND power generation. Any additional electricity sales are deal with as ELEC Sales (Section 8.3.2).

8. ELECTRICITY

8.1. Structure of the ELEC portfolio calculation

Figure 18 shows how thermal generation fits into the electricity supply chain.

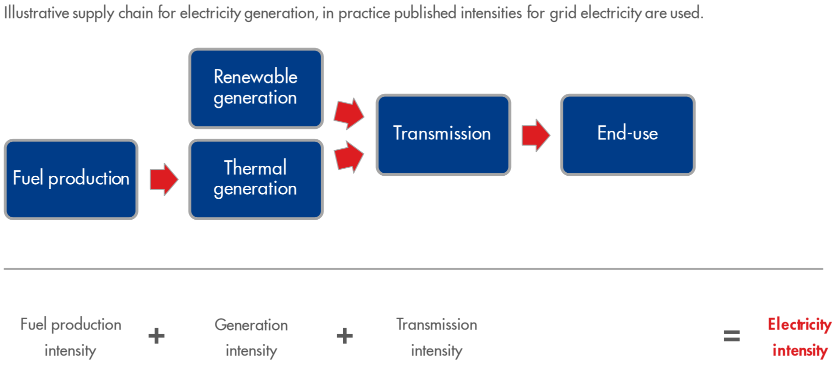

Figure 18 – Shell power plants make up the Thermal generation part of the ELECTRICITY supply chain

The NCF calculation works through a list of Shell ELEC production assets, described by:

- Power generation intensity in gCO_2e/kWh (including the fuel supply for integrated or non-gas plants).
- Total power generated in GWh/year.
- Power generation efficiency, used to calculate the fuel demand.
- Gas fuel fraction (100% for gas-fired, less than 100% for gas co-firing, or zero for non-gas plants)

The life cycle is completed by:

- Conversion of final energy in MJ of electricity to MJ of fossil energy equivalent (See Section 7.1).
- No account is taken of distribution losses on the grid.

8.2. Input data for the ELEC calculation

Provision is made in the model for a pipeline to transport gas to the power plant (as it is for LNG and GTL plants). Pipeline transport of gas to the power plant uses the same emissions intensity and loss factors defined in Section 3.2 but powergen takes place close to the source of gas production, so this distance is currently set to zero.

The Shell share of electricity sales supplied by 3rd parties are included in the NCF. Electricity volumes traded in power markets are included except for pure trading activity.

Grid average intensities are used for 3rd party electricity based on the country of sale, and more local grid intensities are used if a credible data source exists for the intensity. For example, U.S. electricity CI is a weighted average of state electricity CI from the GREET model [4] based on Shell purchase agreements. If country specific emissions intensities are not available, then an appropriate regional or global intensity is used.

8.3. The methodology for the ELEC Portfolio

8.3.1. ELEC Processed calculation

The ELEC Processed calculation is driven from the list of thermal powergen assets.

The purpose of the ELEC Processed calculation is to calculate the WtW intensity of all Shell-processed electricity. Building a well-to-wheel pathway for each Shell power plant may involve feed gas from Shell or non-Shell production.

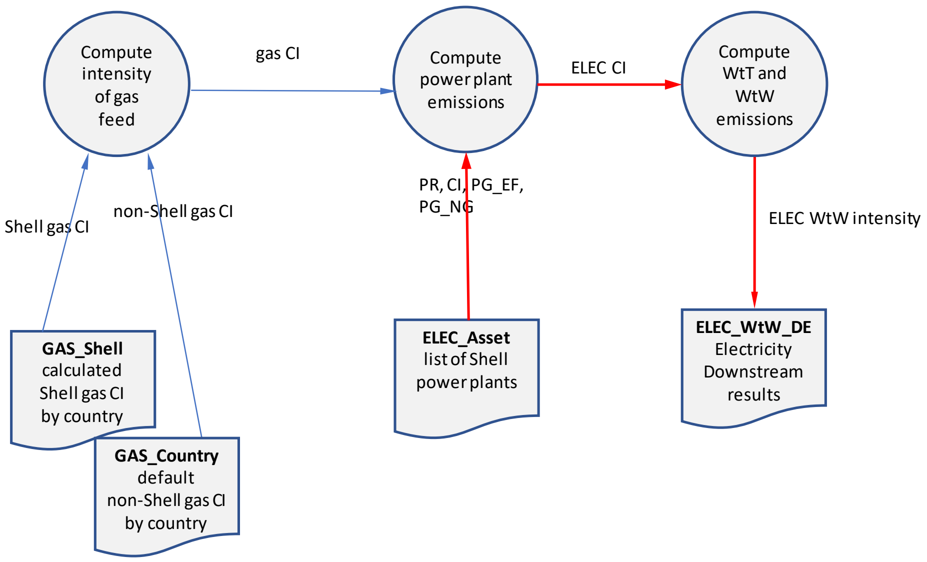

Figure 19 - ELEC Processed data flow diagram

- For each Shell power plant, we determine the amount of gas feed needed from its efficiency and the fraction of fuel input made up by natural gas.
  (If the power plant is an integrated gas power plant, or a power plant that does not consume natural gas, the intensity of the gas supply is not used because these emissions are already included in the power plant intensity.)
- First, we look to country-average Shell gas production to supply the plant. The intensity is taken from the Gas Balance. Total Shell in-country production may not be enough to satisfy all the gas processed by the power plant.
- If there is a shortfall in feed gas, we next look to country-average non-Shell gas production to fill the gap.
- A composite gas production intensity is calculated as a weighted average of both gas sources.

8.3.2. ELEC Sales calculation

The ELEC Sales calculation is driven from a list of Shell electricity sales volumes. These sales are additional to Shell production, and historically have been netted out to avoid double-counting. Revised reporting from 2019 onwards will mean this correction is no longer required.

Electricity sales are assumed to be in addition to electricity production from solar and wind assets.

8.4. Implementation of the calculation methodology for the ELEC portfolio

8.4.1. Acronyms, abbreviations and variables

The list of core acronyms and abbreviations used by the SOLAR/WIND/ELEC portfolio calculation are given in Table 4.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	Carbon intensity in units of CO_2e/MJ	11	LHV	Lower Heating Value
2	A	Asset	12	SD	Shipping distance
3	t	time	13	PD	Pipeline distance
4	Pr	Production	14	veh	Vehicle
5	$Elec$	Power generation	15	shp	Shipping
6	Eff	Power plant efficiency	16	$Port$	Portfolio
7	Gf	Gas fraction of fuel input	17	pd	Pipeline distance
8	Ci	Carbon intensity in $kgCO_2e/boe$	18	GC	Gas consumption
9	WtT	Well to Tank	19	GL	Gas loss as fuel
10	WtW	Well to Wheel	20	Gp	Gas production

Table 6 - Acronyms, abbreviations and variables used in the ELEC calculation

These core notations are used to derive variables used in the model and the report. For example, $CI_{A,t}^{Elec}$ would imply emissions for Asset A at time t (year) due to the process of converting fuel to electricity. Similarly, $CI_{A,t}^{WtW}$ means Well to Wheel emissions for Asset A at time t. We note that all the emissions are expressed in gCO_2e/MJ.

8.4.2. CI calculation

$$CI_{A,t}^{WtT} = [CI_{A,t}^{Gp} * \left(1 + GC_{pipeline}\right) + CI_{pipeline}] * Gf_{A,t}^{elec} / Eff_{A,t}^{Elec} + CI_{A,t}^{Elec} \quad \text{(Eq. 62)}$$

For SOLAR/WIND, there is no fuel supply. For integrated power plants, the emissions of fuel supply are already included in $CI_{A,t}^{Elec}$. In these cases, Equation 62 simplifies to:

$$CI_{A,t}^{WtT} = CI_{A,t}^{Elec} \quad \text{(Eq. 63)}$$

Gas Production

The country-average Shell gas production $CI_{C,t}^{NG}$ is taken from the Gas Balance calculation (Section 3.4.2).

Pipeline to power plant

The pipeline distance, PD, is listed for each asset. Using the appropriate pipeline distance, we can get the total CI up to the point at which gas is delivered to the power plant via the pipeline:

$$GC_{A,t}^{Pipeline} = PD * GC_{pipeline} \quad \text{(Eq. 64)}$$

$$CI_{A,t}^{Pipeline} = PD * CI^{Pipeline} \quad \text{(Eq. 65)}$$

$GC_{pipeline}$ is the gas consumption in t/t-km. $CI^{Pipeline}$ is the intensity in gCO_2e/MJ.

Power generation

The life cycle is completed with the powerplant emissions. For Asset A in year t:

$$CI_{A,t}^{Elec} \quad \text{(Eq. 66)}$$

8.4.3. Portfolio CI of ELEC - Processed view

For each Shell power plant, we determine the amount of gas feed needed $Pr_{A,t}^{NG}$.

$$Pr_{A,t}^{NG} = \left(1 + GC_{pipeline}\right) * Gf_{A,t}^{elec} / Eff_{A,t}^{Elec} * Pr_{A,t}^{Elec} \quad \text{(Eq. 67)}$$

Then we check the Gas Balance to see if there is any surplus gas after in-country LNG and GTL plants have been supplied:

$$Pr_{(A,Elec),t}^{NG\_Sur} = Pr_{c,t}^{NG} - (Pr_{c,t}^{NG\ for\ LNG} - \sum_A Pr_{A,t}^{Dedicated\ NG\ for\ LNG} + Pr_{c,t}^{NG\ for\ GTL} + Pr_{c,t}^{NG\ for\ Elec}) \quad \text{(Eq. 68)}$$

Where $Pr_{c,t}^{NG}$, $Pr_{c,t}^{NG\ for\ LNG}$, $Pr_{A,t}^{Dedicated\ NG\ for\ LNG}$ are described and calculated in Section 3.4.2.

If surplus gas is not enough for the power plant ($Pr_{(A,GTL),t}^{NG\_Sur} < Pr_{GTL,t}^{NG}$), 3rd party gas from is sourced to fill the gap.

$$CI_{(A,Elec),t}^{NG} = \frac{\sum_A CI_{A \in C,t}^{NG} * Pr_{(A,Elec),t}^{NG\_Sur} + CI_{C,t}^{NG} * (Pr_{Elec,t}^{NG} - Pr_{(A,Elec),t}^{NG\_Sur})}{Pr_{Elec,t}^{NG}} \quad \text{(Eq. 69)}$$

Then $CI_{(A,Elec),t}^{NG}$ replaces $CI_{A,t}^{Gp}$ in Eq. 62 for WtT CI calculation.

The portfolio WtW CI at time t is:

$$CI_{Port,t}^{WtW} = \frac{\sum_A P_{Elec,t} * CI_{Elec,t}^{WtT}}{\sum_A P_{Elec,t}} \quad \text{(Eq. 70)}$$

8.4.4. Portfolio CI of ELEC - Sales view

Sales of purchased electricity are similar, except that the WtT intensity is taken as a data input, not calculated from power plant and fuel supply intensities.

The portfolio WtW CI at time t is:

$$CI_{Port,t}^{WtW} = \frac{\sum_A P_{Elec,t} * CI_{Elec,t}^{WtT}}{\sum_A P_{Elec,t}} \quad \text{(Eq. 71)}$$

The contribution of electricity sales to the NCF is then the sum of Shell electricity production and sales of purchased electricity.

9. Portfolio Net Carbon Footprint

The Net Carbon Footprint of Shell's portfolio is the average emissions intensity of all supply chains weighted by final energy delivered to the end-user. The final energy may be less than the amount processed by Shell if some product is consumed in transit (as in LNG shipping) or more than Shell production when supplemented by sales of bought-in products.

9.1. Input data for Portfolio NCF

The input to the portfolio average calculation are the results of the individual supply chain calculations detailed in the previous chapters.

9.2. Implementation of the methodology for the Portfolio NCF

9.2.1. Acronyms, Abbreviations and variables

The list of core acronyms and abbreviations used in this section are given in Table 7.

No.	Notation	Explanation	No.	Notation	Explanation
1	CI	GHG Emissions intensity (in gCO_2/MJ)	5	NCF	Net Carbon Footprint (in gCO_2e/MJ)
2	t	time	6	FE	Final energy delivered to end-users (in MJ)
3	$Port$	Portfolio	7	WtW	Well to Wheel
4	S	Supply chain			

Table 7 - Acronyms, abbreviations and variables used for NCF calculations

The above abbreviations can be used to describe the variables used in the model and in this report. Thus, $CI_{S,t}^{WtW}$ would mean WtW emissions in gCO_2e/MJ for the supply chain S at time t.

9.2.2. CI calculation

$NCF_{Port,t}^{WtW}$ is the portfolio intensity in gCO_2e/MJ. It is calculated as follows:

$$NCF_{Port,t}^{WtW} = \frac{\sum_S CI_{S,t}^{WtW} \times FE_S}{\sum_S FE_S} \quad \text{(Eq. 72)}$$

10. CO_2 Sinks

Total portfolio emissions can be reduced when active measures are taken to capture CO_2 that would otherwise have been emitted or to offset CO_2 emissions though projects that capture CO_2 from the atmosphere or increase carbon storage in soil, referred to as "nature-based solutions" (NBS).

10.1. Input data for CO_2 sinks

CO_2 reductions at individual assets can be captured in the asset emissions intensity or treated as a stand-alone CO_2 sink so long as double counting is avoided.

CO_2 volumes currently captured by the Quest carbon capture and storage facility are accounted for in the emissions reported by the Scotford complex. CCS from all future qualifying projects will also be included. Shell may choose to use carbon credits to offset emissions, these will be accounted for in the NCF providing they meet eligibility criteria regarding their use and retirement.

10.2. Implementation of the calculation methodology for the CO_2 sinks

If CO_2 emissions are not captured at an asset level, then they are accounted for by first calculating total CO_2e emissions from the average portfolio intensity. This is then reduced by the total CO_2 absorbed in the sinks and an adjusted intensity calculated.

10.2.1. Acronyms, Abbreviations and variables

The list of core acronyms and abbreviations used in this section are given in Table 8.

No.	Notation	Explanation	No.	Notation	Explanation
1	*CI*	GHG Emissions intensity (in gCO_2/MJ)	4	*CI'*	Adjusted GHG Emissions intensity (in gCO_2/MJ)
2	*t*	time	5	*WtW*	Well to Wheel
3	*Port*	Portfolio	6	CO_2	Sum of all CO_2 reductions (in g)
			7	*FE*	Final energy delivered to end-users (in MJ)

Table 8 - Acronyms, abbreviations and variables used for CO_2 Sinks calculations

The above abbreviations can be used to describe the variables used in the model and in this report. Thus, $CI_{Port,t}^{WtW}$ would mean WtW emissions in gCO_2e/MJ for the Portfolio at time t.

10.2.2. CI calculation

Total CO_2e emissions are calculated from the average portfolio intensity. These are then reduced by the total CO_2 absorbed in the sinks and an adjusted intensity calculated.

$CI'^{WtW}_{Port,t}$ is the portfolio intensity in gCO_2e/MJ, adjusted for CO_2 sinks. It is calculated as follows:

$$CI'^{WtW}_{Port,t} = \frac{Port*FE_{Port}-CO_2}{FE_{Port}} \quad \text{(Eq. 73)}$$

APPENDIX 1. GLOSSARY

bbl	Barrel of oil (a unit of volume)
boe	Barrel of oil equivalent (a unit of energy = 5.8 mm BTU gross calorific value)
CCS	Carbon Capture and Storage
CI	Carbon intensity
CO_2e	CO_2 equivalent of CO_2, CH_4 and N_2O emissions
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FAME	Fatty Acid Methyl Esther
GHG	Greenhouse gas
GREET	The Greenhouse gases, Regulated Emissions, and Energy use in Transportation model
GTL	Gas-to-Liquid
IEA	International Energy Agency
JEC	Joint Research Centre (JRC)-EUCAR-CONCAWE collaboration
LNG	Liquefied Natural Gas
LUC	Land Use Change
MDO	Marine diesel oil
NBS	Nature-Based Solutions (a form of carbon capture)
NCF	Net Carbon Footprint
NETL	U.S. National Energy Technology Laboratory
NG	Natural Gas
OPGEE	The Oil Production Greenhouse gas Emissions Estimator
RDS	Royal Dutch Shell
RFS	U.S. Renewable Fuel Standards
TtW	Tank-to-Wheel (end-use)
WtT	Well-to-Tank
WtW	Well-to-Wheel

APPENDIX 2. OIL EXPORTS AND TRANSPORT/SHIPPING DISTANCE

A.2.1. Pipeline transport mode

Generic assumptions	
Across regions [35]	2000 km
Specific assumptions	
Within Argentina[8] [32]	492 km
Within Canada [33]	1698 km
Within Europe [38]	250 km
Within Malaysia[9] [36]	217 km
Within Saudi Arabia [37]	1200 km
Within U.S. [34]	161 km

Figure A1 - Assumed distance for oil transport via pipeline

A.2.2. Shipping transport mode

The median values of the shipping distances were provided by the Shell International Trading and Shipping team. For countries where distances were not available, the distance was estimated by the following approach.

The quantity of oil shipped inter-regionally in mbbl/d was found in the Oil Medium-Term Market Report 2014 by the International Energy Agency [5]. To find an estimate of the shipping distances for the transport of oil between the regions, the most active shipping and receiving oil terminals were found in each region and the closest port then determined. Where possible, this was conducted by comparing quantitative data published online about oil capacity and turnover. However, this was not possible when the list of oil terminals in a region wasn't particularly extensive or if it was difficult to determine the most active oil terminals in a region due to the parameters available to rank them not being consistent. When the most active terminals in a region could not be easily determined, the biggest oil importing/exporting country in the region was found in a publication by the U.S. Energy Information Administration [27]. The most

[8] Capacity weighted average of oil pipelines
[9] Average of main pipelines, small pipelines excluded (<10-15km)

appropriate port in that country was then found by proximity to the oil terminals. Below is a list of the oil terminals/country used for each region, with the port used to determine shipping distances in brackets.

Receiving terminals:

- North America - Louisiana Offshore Oil Port, USA (New Orleans port)
- Latin America – Chile (Gregorio)
- Africa – South Africa (Durban)
- EU - Wesseling, Germany (Wilhelmshaven)
- MENA (Qatar) - Israel (Haifa)
- Japan & Oceanian (OECD Asia) – Japan (Chiba)
- China - CRC Oil Storage Depot, China (Hong Kong)
- Asia (India for import) - Butcher Island, India (Mumbai)

Shipping terminals:

- North America – Canaport, Canada (Saint John's port)
- Latin America – Orinoco Belt, Venezuela (Port Cabello)
- Africa – Nigeria (Port Harcourt)
- EU – Norway (Oslo)
- MENA (Qatar) - Al Basrah oil terminal, offshore Iraq (Basrah)
- Japan & Oceania (OEDC Asia) – Indonesia (Jakarta)
- China (Singapore) – China (Hong Kong)
- Asia (Russia for export) - Tuapse oil terminal, Russia (Tuapse)

Shipping distances between the regions were calculated using a shipping distance calculator [6].

APPENDIX 3. GAS EXPORTS AND TRANSPORT/SHIPPING DISTANCE

A.3.1. Pipeline transport distances

Specific assumptions	(in order of importance)
Netherlands	285 km
U.S.	971 km
Canada	2233 km
Norway	736 km
United Kingdom	900 km
Bolivia	1725 km
Germany	100 km
Generic assumptions	
Kazakhstan, Azerbaijan, Mongolia	2500 km
All others	1200 km

Figure A2 - Assumed distance for gas transport via pipeline

This distance is used only for countries which export gas by pipeline (not LNG).

A.3.2. Pipeline transport distances

Pipeline distances were assessed for Shell's most important gas-producing countries by volume, detailed below.

Netherlands

EIA data shows the Netherlands producing 1601 bcf in 2017, consuming 1532 bcf, importing 1801 bcf and exporting 1810 bcf (https://www.eia.gov/international/overview/country/NLD). 2017 is the latest year for which data are available.

Imports and exports each account for roughly 50% of total gas movements.

Domestic pipeline can be represented by Groningen-Rotterdam distance of 250km.

CBS paper https://www.cbs.nl/-/media/_pdf/2019/27/international-gas-trade-in-the-netherlands.pdf shows exports to be divided: Germany 50%, Belgium 40%, UK 10%. Represent

NL-Germany by Groningen-Essen distance of 275km

NL-Belgium by Groningen-Brussels distance of 400km

NL-UK distance by the length of the BBL and Zeebrugge-Bacton interconnectors, 235km

Average NL pipeline distance is then 50%*250 + 50%*(50%*275+40%*400+10%*235)= 285 km

United States

A distance of 971 km was assumed by NETL in their 2014 study of the LCA of U.S. powergen [28].

Canada

A distance of 2233 km is used in the Canadian GHGenius model [29].

Norway

Averaging export pipeline lengths in Norway (and assuming that domestic consumption is negligible by comparison):

Europipe I, 420 km, 18 bsm3/y capacity

Europipe II, 643 km, 24 bsm3/y

Norpipe, 354 km, 16 bsm3/y

Langeled, 1166 km, 25 bsm3/y

Zeepipe, 814 km, 15 bsm3/y

Franpipe, 840 km, 20 bsm3/y

Weighted average length = 736km

United Kingdom

EIA data show the UK to be a net importer of natural gas, so UK gas producing assets are assumed to route gas 100% to the UK.
https://www.eia.gov/international/data/country/GBR/natural-gas

The distance from the gas fields in the southern North Sea to shore is assumed to be half the length of the NL-UK distance by the length of the BBL and Zeebrugge-Bacton interconnectors, 50%*235km = 118 km.

Feeder lines from Bacton and Easington terminals to the National Gas Transmission System average 190km. Add to this the length of the NTS spine (Canvey Island-Leeds) 320km. (https://en.wikipedia.org/wiki/National_Transmission_System)

Total UK pipeline length is 118 + 190 + 320 = 628km

Bolivia

EIA data shows Bolivia producing 660 bcf in 2017, consuming 112 bcf, importing 0 bcf and exporting 546 bcf (https://www.eia.gov/international/overview/country/BOL). Exports account for 80% of Bolivia's gas

Domestic pipeline can be represented by Yabog pipeline distance of 441km.

International pipeline can be represented by GASBOL pipeline distance of 2046km

Average pipeline distance is then 20%*441 + 80%+2046 = 1725km.

Germany

In Germany, Shell produces gas in Niedersachsen (just south of Bremen) and, as Germany is a net gas importer, this gas can be put onto the local grid without the need to transport it large distances

For our purposes, pipeline transport is assumed to be the distance from Nienburg (the centre of gravity of Shell projects) to Bremen, 100km. (https://reports.shell.com/investors-handbook/2018/servicepages/worldmap.php.)

Kazakhstan, Azerbaijan, Mongolia

These countries resemble Canada, in that gas is transported across continental distances. An estimated distance of 2500km has been used (similar to Canada's 2233km).

Others

A proxy value of1200km is assumed for all other countries, used when more accurate data are not available. It can be seen that, by comparison with most of the countries above, it is a conservative choice.

APPENDIX 4. APPENDIX 4. LNG SHIPPING DISTANCES

In order to calculate LNG shipping distances the following steps were taken:

1. Using the LNG trade volumes between markets [9], exporting countries were identified e.g. Algeria
2. Using the LNG trade volumes between markets [9], largest importing countries (by volume) in their respective regions were identified e.g. China within Asia.
3. Within the exporting country, the largest liquefaction terminal by capacity [9] is taken as the reference terminal
4. Within the largest importing country, the largest receiving terminal [9] by capacity is taken as the reference terminal for that region
5. Shipping distances were calculated between the reference terminals of both exporting and importing countries using sea distance calculator [6].
6. Shipping distances are recorded in 'NCF_LNG_Input_Processing' file under 'Shipping_Distances' sheet.

Receiving terminals:

- Mexico - Costa Azul
- Chile - Quintero
- Spain - Barcelona
- Kuwait - Mina Al Ahmadi
- Japan - Chiba
- China - Guangzhou

Shipping terminals:

- Algeria – Arzew
- Angola – Cabinda
- Australia – Darwin
- Brunei Darussalam – Seria
- Cameroon – Douala (FLNG)
- Egypt – Alexandria
- Equatorial Guinea – Punta Europa Terminal
- Indonesia – Samarinda
- Malaysia – Sibu
- Nigeria – Bonny
- Norway – Hammerfest
- Oman – Muscat
- Papua New Guinea – Port Moresby

- Peru – Pisco
- Qatar – Doha
- Russian Federation – Vladivostok
- Trinidad and Tobago – Point Fortin
- United Arab Emirates – Das Island
- United States – Sabine

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Cautionary note

The companies in which Royal Dutch Shell plc directly and indirectly owns investments are separate legal entities. In this report "Shell", "Shell Group" and "Royal Dutch Shell" are sometimes used for convenience where references are made to Royal Dutch Shell plc and its subsidiaries in general. Likewise, the words "we", "us" and "our" are also used to refer to Royal Dutch Shell plc and its subsidiaries in general or to those who work for them. These terms are also used where no useful purpose is served by identifying the particular entity or entities. ''Subsidiaries'', "Shell subsidiaries" and "Shell companies" as used in this report refer to entities over which Royal Dutch Shell plc either directly or indirectly has control. Entities and unincorporated arrangements over which Shell has joint control are generally referred to as "joint ventures" and "joint operations", respectively. Entities over which Shell has significant influence but neither control nor joint control are referred to as "associates". The term "Shell interest" is used for convenience to indicate the direct and/or indirect ownership interest held by Shell in an entity or unincorporated joint arrangement, after exclusion of all third-party interest.

Also, in this report we may refer to Shell's "Net Carbon Footprint", which includes Shell's carbon emissions from the production of our energy products, our suppliers' carbon emissions in supplying energy for that production and our customers' carbon emissions associated with their use of the energy products we sell. Shell only controls its own emissions. But, to support society in achieving the Paris Agreement goals, we aim to help such suppliers and consumers to likewise lower their emissions. The use of the term Shell's "Net Carbon Footprint" is for convenience only and not intended to suggest these emissions are those of Shell or its subsidiaries.

This report contains forward-looking statements (within the meaning of the U.S. Private Securities Litigation Reform Act of 1995) concerning the financial condition, results of operations and businesses of Royal Dutch Shell. All statements other than statements of historical fact are, or may be deemed to be, forward-looking statements. Forward-looking statements are statements of future expectations that are based on management's current expectations and assumptions and involve known and unknown risks and uncertainties that could cause actual results, performance or events to differ materially from those expressed or implied in these statements. Forward-looking statements include, among other things, statements concerning the potential exposure of Royal Dutch Shell to market risks and statements expressing management's expectations, beliefs, estimates, forecasts, projections and assumptions. These forward-looking statements are identified by their use of terms and phrases such as "aim", "ambition", ''anticipate'', ''believe'', ''could'', ''estimate'', ''expect'', ''goals'', ''intend'', ''may'', ''objectives'', ''outlook'', ''plan'', ''probably'', ''project'', ''risks'', "schedule", ''seek'', ''should'', ''target'', ''will'' and similar terms and phrases. There are a number of factors that could affect the future operations of Royal Dutch Shell and could cause those results to differ materially from those expressed in the forward-looking statements included in this report, including (without limitation): (a) price fluctuations in crude oil and natural gas; (b) changes in demand for Shell's products; (c) currency fluctuations; (d) drilling and production results; (e) reserves estimates; (f) loss of market share and industry competition; (g) environmental and physical risks; (h) risks associated with the identification of suitable potential acquisition properties and targets, and successful negotiation and completion of such transactions; (i) the risk of doing business in developing countries and countries subject to international sanctions; (j) legislative, fiscal and regulatory developments including regulatory measures addressing climate change; (k) economic and financial market conditions in various countries and regions; (l) political risks, including the risks of expropriation and renegotiation of the terms of contracts with governmental entities, delays or advancements in the approval of projects and delays in the reimbursement for shared costs; and (m) changes in trading conditions. No assurance is provided that future dividend payments will match or exceed previous dividend payments. All forward-looking statements contained in this report are expressly qualified in their entirety by the cautionary statements contained or referred to in this section. Readers should not place undue reliance on forward-looking statements. Additional risk factors that may affect future results are contained in Royal Dutch Shell's Form 20-F for the year ended December 31, 2019 (available at www.shell.com/investor and www.sec.gov). These risk factors also expressly qualify all forward-looking statements contained in this [report] and should be considered by the reader. Each forward-looking statement speaks only as of the date of this report, 24th November 2020. Neither Royal Dutch Shell plc nor any of its subsidiaries undertake any obligation to publicly update or revise any forward-looking statement as a result of new information, future events or other information. In light of these risks, results could differ materially from those stated, implied or inferred from the forward-looking statements contained in this report.

We may have used certain terms, such as resources, in this report that the United States Securities and Exchange Commission (SEC) strictly prohibits us from including in our filings with the SEC. U.S. investors are urged to consider closely the disclosure in our Form 20-F, File No 1-32575, available on the SEC website www.sec.gov.

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