# Shell's Net Carbon Footprint: Methodology

## Net Carbon Intensity

Shell Global Solutions (UK) (a division of Shell Research Ltd.)

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# Executive Summary

The energy products sold by Shell include liquid fuels such as gasoline and diesel, natural gas in the form of pipeline gas, liquefied natural gas (LNG), or gas-to-liquid (GTL) products, biofuels, and power from conventional and renewable sources.

Shell has developed a net carbon footprint (NCF) methodology for quantifying and tracking the greenhouse gas (GHG) emission intensity of the entire lifecycle 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 and outlines the boundary, scope, and assumptions used in the net carbon intensity (NCI) calculation. The scope of the methodology includes Shell's principal energy product supply chains as shown in Figure 1.

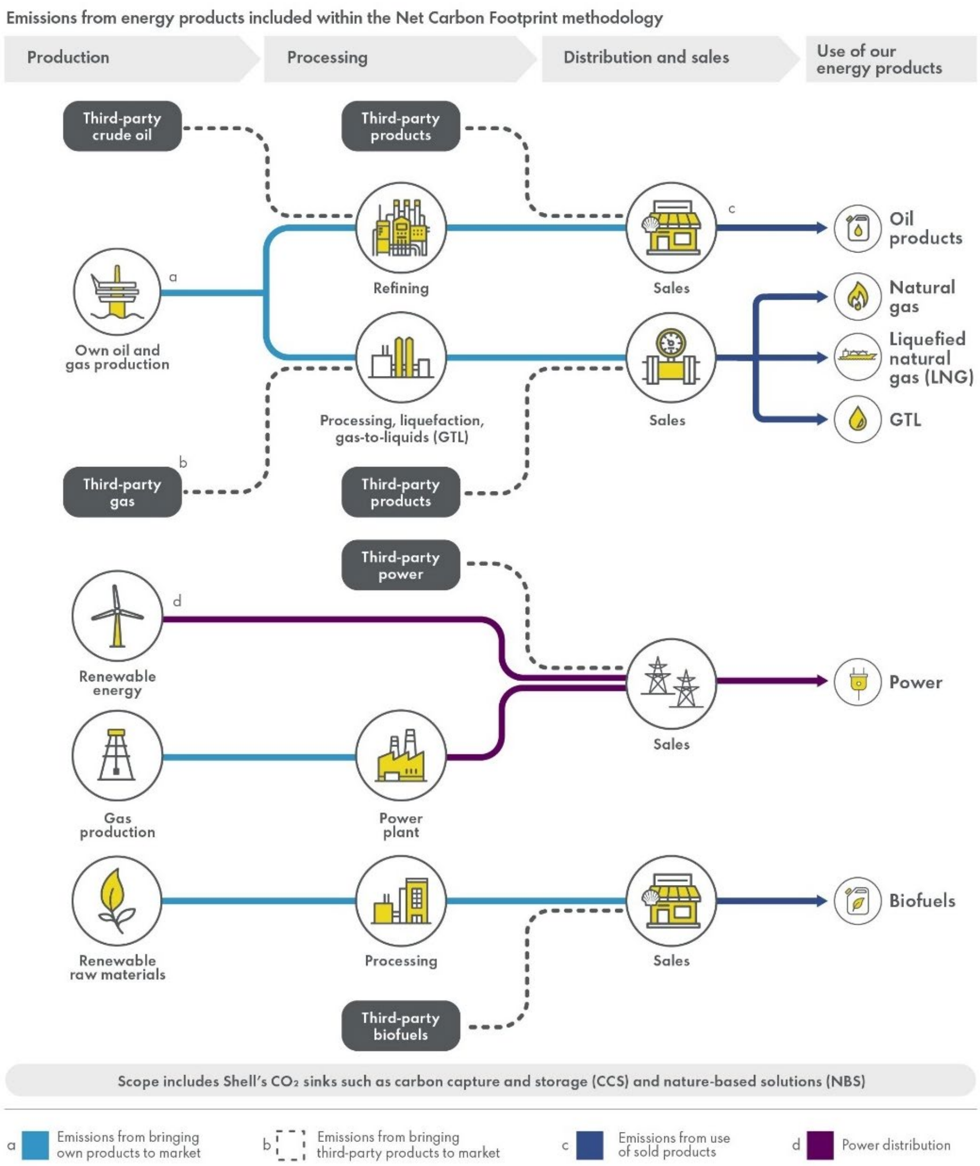



Figure 1: The scope of Shell's net carbon footprint methodology (from Shell's Annual Report and Accounts 2021).

# Contents

# 1. Introduction

This document outlines the detailed methodology used in calculating Shell's Net Carbon Intensity (NCI) metric. First, an overview of the methodology is provided covering the:

- approach to the NCI calculation including boundaries and scope;
- implementation of the NCF methodology including a high-level review of inputs; and,
- review of the formula notation used throughout the report.

This is followed by a description of the lifecycle calculations completed for each of Shell's principal energy product pathways including:

- an overview of the product lifecycle pathway;
- the methodology for calculating the lifecycle carbon intensity; and,
- the implementation details including assumptions and input data requirements as well as calculation details.

This document is periodically revised to reflect any updates made to the methodology, and its implementation, in response to changes in Shell's energy product portfolio.

Note that this document uses the following terminology: the net carbon footprint (NCF) methodology is used to calculate the net carbon intensity (NCI). Net absolute emissions (NAE) can also be derived from the NCI and total energy sales.

# 2. Shell's NCF Methodology

## 2.1. Approach

### 2.1.1. Introduction

Shell's Net Carbon Footprint methodology uses a combination of data from Shell's operations, along with publicly and commercially available data, to determine a lifecycle emission intensity for each of the energy pathways (supply chains) included in Shell's energy product portfolio. Shell's product sales, on an energy basis, are then used to determine the relative proportion of each of the products in the portfolio and give the individual intensities the correct weighting in the final calculation of the Net Carbon Intensity. Accordingly, the NCI is defined as the weighted average lifecycle emission intensity of the portfolio of energy products sold by Shell.

The emission intensity of each of the different energy products sold by Shell is calculated on a full lifecycle basis, meaning emissions from the production of unrefined hydrocarbons through to the end-use of processed products are included. Lifecycle analysis assesses the emission impact at each stage of the product's production and subsequent end-use (Figure 2). While the full pathway assessed includes end-use, lifecycle intensity values calculated are represented at the "sales" stage shown in Figure 2. This means the volume of energy used in the calculation is the total volume of energy products sold by Shell.

This approach differs from a more traditional well-to-wheel lifecycle analysis where the functional unit is based on the energy service delivered, e.g. $gCO_2e$ per km for fuel usage in a passenger car. Shell has chosen to use the functional unit of $gCO_2e$ per unit of energy delivered and used, as this allows the lifecycle emissions intensities of different energy products, with diverse end-uses, to be aggregated into a single value. For similar reasons, the functional unit is based on energy content rather than a volumetric measure of product delivered as this also simplifies the aggregation of different energy product intensities.

During the calculation of the NCI, emissions abated using technologies like carbon capture and storage (CCS) are deducted at the appropriate stage (i.e. incorporated in the stage's characteristic intensity). The NCI calculation also deducts any emissions offset using carbon credits. These offsets are not embedded in the individual energy pathways and instead are included in the final portfolio level calculations.

### 2.1.2. Overview of the NCI calculation

In the energy sector, multiple activities (operations) are required to extract sources of energy like crude oil and natural gas, transform them into energy products, and finally distribute them prior to their sale. These operations can be represented by a generalised lifecycle pathway which includes the stages of production, transportation, processing, distribution, and product use (Figure 2). GHGs can be emitted at each stage in the product lifecycle, and similarly efforts can also be made to mitigate emissions at various points in the pathway. Abatement opportunities include the use of technologies such as carbon capture and storage (CCS) at processing facilities, carbon credits can also be used to offset emissions.

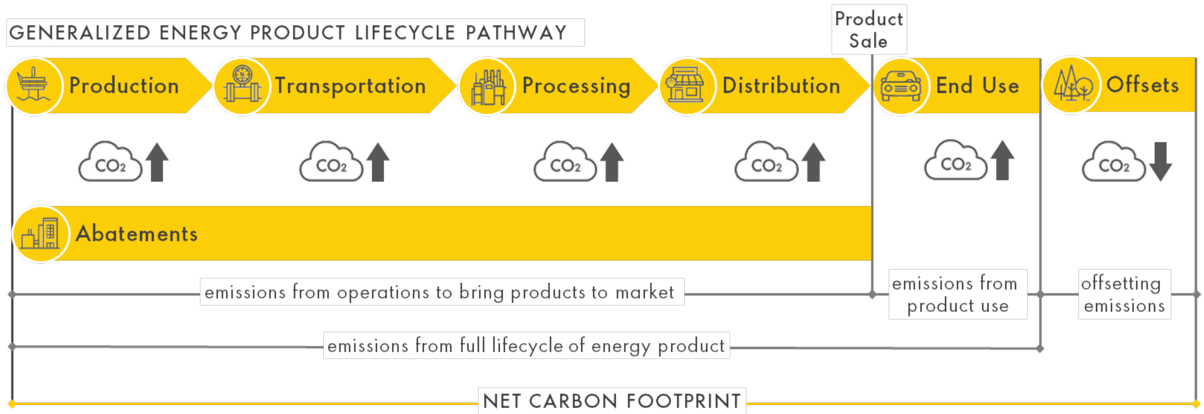



**Figure 2:** Generic energy product lifecycle pathway.

To assist in comparisons of different energy products it is common to describe the lifecycle emissions from an energy product in terms of the emission intensity (carbon intensity[1], CI). A carbon intensity, in its most generalized form, is the ratio of the GHG released (typically by weight or volume) per unit of output. Each operation in an energy product pathway (Figure 2) can be ascribed a characteristic intensity which describes the contribution of that stage to the overall lifecycle intensity. The lifecycle intensity is then the summation of the characteristic intensity for each stage in the energy product pathway including end-use:

$$CI^{Lifecycle} = CI^{Production} + CI^{Transport} + CI^{Processing} + CI^{Distribution} + CI^{End\ Use} \quad \text{(Eq. 01)}$$

Abatement can be incorporated into the characteristic intensity of the relevant stages.

Shell's NCI is estimated by first calculating the lifecycle CI of each of the energy products sold by Shell. A weighted average CI ($CI^{Portfolio\_Gross}$) for all energy products sold is then calculated with the weighting for the individual product CIs ($CI^x$) determined by their contribution ($E^x$) to the total energy product sales ($E^{Total}$):

$$CI^{Portfolio\_Gross} = \sum_x \left( CI^x * \frac{E^x}{E^{Total}} \right) \quad \text{(Eq. 02)}$$

The net emissions associated with the energy products sold by Shell can then be calculated using the portfolio CI, the total energy sales, and the volume of emissions offset:

$$GHG^{Net} = (CI^{Portfolio\_Gross} * E^{Total}) - GHG^{Offset} \quad \text{(Eq. 03)}$$

The net emissions can then be used to calculate the NCI ($CI^{Portfolio\_Net}$) which includes the impact of any emissions offset:

$$CI^{Portfolio\_Net} = \frac{GHG^{Net}}{E^{Total}} \quad \text{(Eq. 04)}$$

[1] Emissions are often expressed in terms of their carbon dioxide equivalence and as a result emission intensity is commonly referred to as carbon intensity, the terms carbon intensity and emission intensity are used interchangeably throughout this document.

Intensity metrics, such as the NCI, can be used to track the rate of decarbonisation of the complete portfolio of energy products sold by an energy supplier. Shell's approach to setting targets based on the NCI metric is described in the 2021 Shell Energy Transition Strategy [1].

### 2.1.3. Scope and Boundaries

The scope and boundaries of the NCI calculation are selected to ensure:

- that changes in the portfolio of sold energy products are properly reflected in the NCI trends;
- that changes in the emission intensity of any individual product are also properly reflected; and,
- that there are no material omissions within the scope, such that the NCI trends represent the overall rate of decarbonisation of the energy products sold by Shell

Although the underlying NCF methodology is well established, the scope evolves as new energy product pathways are added to Shell's portfolio.

The NCF methodology currently covers the six principal energy product pathways in Shell's energy product portfolio (Figure 3): 1) oil products, 2) pipeline natural gas, 3) liquified natural gas (LNG), 4) gas-to-liquid (GTL) fuels, 5) biofuels, and 6) power. Non-energy products such as chemicals, lubricants and bitumen are outside the scope of the NCF methodology because the end-use of these products is generally not to be consumed as fuel.

The lifecycle analysis of each energy product pathway includes: the acquisition of raw materials, transport of raw materials, processing of materials for products, distribution of processed products, and end-use of products. For each of the principal product pathways, the following stages are captured:

- Oil products: (i) crude oil production, (ii) transportation of crude oil (pipeline/shipping), (iii) refining, (iv) distribution of oil products, and (v) oil-product combustion.
- Pipeline gas: (i) gas production & processing, (ii) transportation of gas via pipeline, and (iii) gas combustion.
- LNG: (i) gas production & processing, (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) gas combustion.
- GTL: (i) gas production & processing, (ii) transportation of gas via pipeline, (iii) gas-to-liquid processing, (iv) shipping of GTL products, (v) local distribution of GTL fuel products, (vi) GTL combustion.
- Biofuels: (i) production, (ii) transportation (domestic/shipping), (iii) distribution and (iv) biofuel combustion.
- Electricity: For non-renewable power generation, the stages are: (i) fuel production & processing, (ii) thermal generation, (iii) transmission, and (iv) end-use. For solar and wind power generation, the stages are: (i) renewable generation, (ii) transmission, and (iii) end use.

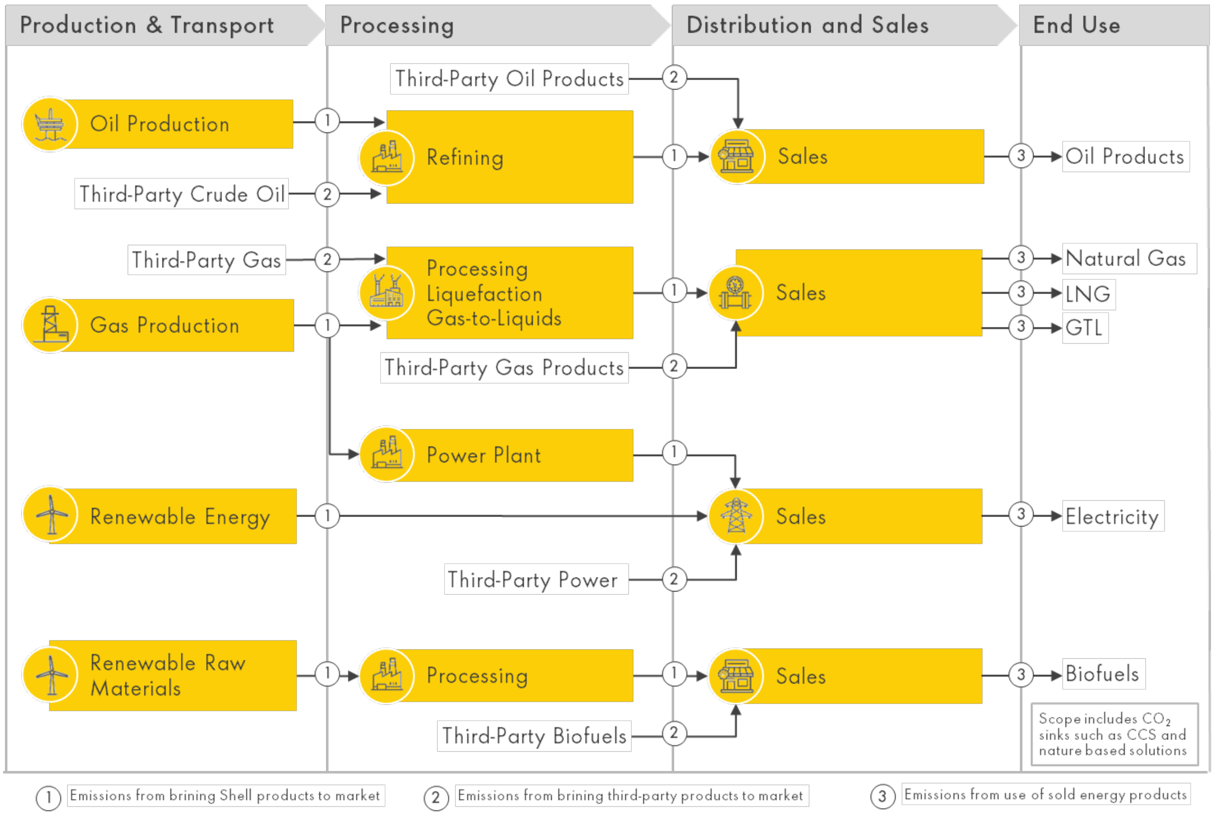



**Figure 3:** Schematic of the principal energy pathways (supply chains) in Shell's portfolio.

The NCI calculation uses Shell's energy product sales volume data as disclosed in the Annual Report and Sustainability Report. This excludes certain contracts held for trading purposes and reported net rather than gross. Business-specific methodologies to net volumes have been applied in oil products, pipeline gas and power. Paper trades that do not result in physical product delivery are excluded. Retail sales volumes from markets where Shell operates under trademark licensing agreements are also excluded from the scope of Shell's NCI.

The lifecycle intensity analysis for products produced by 3rd parties, but sold by Shell, uses an approach which is consistent with that used for Shell produced products, i.e. the same stages are used in the pathway. However, detailed emissions and/or carbon intensity data for 3rd party producers may not be readily available and must be estimated from publicly available sources. More details on the specific assumptions used in the calculations are provided in subsequent sections.

### 2.1.4. Exclusions

GHG emissions not included in the NCI calculation include:

- emissions from production, processing, use, and end-of-life treatment of non-energy products, such as chemicals and lubricants;
- emissions associated with the construction and decommissioning of production and manufacturing facilities;

- emissions associated with the production of fuels purchased to generate energy onsite;
- other indirect emissions from waste generated in operations, business travel, employee commuting, transmission and distribution losses associated with imported electricity, franchises and investments;
- emissions from 3rd party processing of sold intermediate products; and,
- emissions from capital goods and other goods and services not related to purchased energy feedstocks sourced from 3rd parties or energy products manufactured by 3rd parties and sold by Shell.

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 also include the Scope 3 emissions associated with producing fuel and transporting it to Shell assets, and the production and transport of fuels to our electricity suppliers, accounting for any distribution losses. These items are omitted because:

- the required data to calculate the emissions is insufficient, unavailable, or uncertain; and,
- the impact of these additional energy requirements, and associated emissions, on the total fuel pathway balance is small and within the range of uncertainty of the total estimates when amortized over the life cycle of these facilities.

### 2.1.5. Assumptions

It is not practical to comprehensively track Shell and 3rd party hydrocarbon flows between upstream, midstream, and downstream operations. Some simplifications and assumptions are therefore required to make the calculation of the carbon intensity along the value chains manageable. Assumptions directly related to a specific energy product pathway are described in more detail in subsequent sections.

The NCF methodology uses the principle of net volume accounting where sales are counted at the point of maximum throughput in the value chain. The IPIECA Scope 3 guidelines describe this principle as follows:

> *'To avoid onerous accounting for IO&G companies, such as accounting for the movement of each molecule (e.g. specifying discrete inputs and outputs, such as the specific amount of Company C crude oil used in Company C refineries) companies can use net volume accounting. In net volume accounting companies identify that point in the value chain where the largest total amount of potential sold products is transferred:*
>
> 1) *crude produced;*
> 2) *refinery throughput (refinery throughput is used to enable equivalent comparison between companies that don't have readily available information on refinery output); or*
> 3) *retail and commercial (marketing) operations (i.e. sales to end users).*

> *When sales data to end users are not readily available in a consolidated form, some companies choose instead to use production or refinery data.'* [2]

For Shell, the point of maximum throughput is at the point of sale and therefore the NCF methodology is based on Shell's total sales of energy products, including products produced by 3rd parties, instead of focussing only on the products produced or processed by Shell.

The NCF methodology also assumes that all combustible energy products sold by Shell are combusted, no deductions are made from product sales to account for any non-energy use.

### 2.1.6. Functional Units

Common metrics (functional units) are required to make like-for-like comparisons across a broad range of energy products and establish a single carbon intensity which encompasses all the energy products sold. The functional unit for the NCI calculation is the mass of GHG emissions per unit of energy delivered and used. This means that the NCI is expressed in grams of carbon dioxide equivalent (emissions, $gCO_2e$) per megajoule (energy, MJ) of products delivered and used. Lower heating values (LHV) are used for the energy content of the different products and a fossil fuel equivalence approach is used to account for electrical energy, so that it is assessed on the same basis as other energy products.

## 2.2. Implementation

### 2.2.1. Assurance and applicable standards

Shell annually submits its NCI metric for external verification prior to publication. The aim of external assurance is to confirm that

- the NCF methodology described in this document has been effectively applied; and,
- that Shell has appropriate internal controls in place for critical processes such as data collection and maintenance of the NCF model.

The results of external assurance (*assurance statements*) are published on the Shell Sustainability reporting and performance data website [3]. Shell's NCI, and the carbon intensity of the principal product pathways, is reported in the Annual and Sustainability reports.

The NCF methodology follows ISO standards [4] for life cycle analysis with the following clarifications:

- The NCI applies only to the lifecycle emission intensity of the energy products sold by Shell.
- Chemicals (including lubricants and bitumen) are not energy carriers and are therefore omitted.
- 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

because insufficient data are available to allow these emissions to be calculated. The omission is not considered to be material.[2]

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

### 2.2.2. Calculation Notation

A distinct notation is used to define the calculations used by the NCI model. For a given quantity (intensity, emission, energy) the relevant stage, product pathway, scope, and instance in time are denoted by:

$$Quantity_{scope,time}^{stage,pathway}$$

The scope can include asset type, location, method type, or product type. A description of the nomenclature used is outlined in Table 1.

Formulae distinguish between Shell and 3rd parties using an accent. Using the oil product pathway ($oil$) as an example, $CI_{Ru,t}^{up,oil}$ is the intensity for Shell upstream production at a regional level ($Ru$) while $CI_{Ru,t}^{\overline{up},oil}$ is the intensity for 3rd party upstream production at the same level of aggregation.

[2] 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 emissions. The emissions from the end-use of Shell products are the most significant contribution to the NCI 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 NCI value.

**Table 1: NCI calculation notation**

| Energy Product Pathway | | | |
|---|---|---|---|
| bio | biofuels | GTL | gas to liquids |
| elec | electricity | LNG | liquified natural gas |
| gas | natural gas (pipeline gas) | oil | refined oil products |
| **Pathway Stage** | | | |
| dist | distribution of processed products | ref | processing (refining) of crude oil |
| end_use | use of energy products | ship | transportation of product via ship |
| exp | export transportation of products | sales | sale of energy product |
| local | local transportation of products | up | production (upstream) of raw hydrocarbons |
| liq | liquefaction of natural gas | WtLA | Well-to-Loading Arm; partial lifecycle from gas production to liquefaction stage of LNG pathway |
| MDS | middle distillate synthesis in gas-to-liquids production | WtT | Well-to-Tank; operations portion of lifecycle pathway |
| pipe | transportation of product via pipeline | WtW | Well-to-Wheel or Well-to-Wire depending on energy pathway; Full lifecycle |
| gen | power generation facility | WtG | Well-to-Gate: partial lifecycle up-to and including processing/production |
| **Quantity** | | | |
| CI | emission intensity in $CO_2$ equivalent per energy unit | GHG | greenhouse gas emissions in $CO_2$ equivalence |
| CF | conversion factor | GR | gas reduction factor (e.g. consumption as fuel or loss as fugitive emissions, etc.) |
| D | distance of transportation | TR | Fraction of power loss (reduction) during transmission |
| E | energy content associated with product volume | PE | power generation efficiency ratio (energy of hydrocarbon fuel / electricity output) |
| Eff | efficiency ratio of feedstock intake to product outturn on an energy basis | R | Reduction/loss factor |
| GC | gas consumption factor | V | volume of product |
| GF | gas fuel-fraction; the ratio of fuel intake that is natural gas for power generation. | W | Fractional allocation |

**Table 2: NCI calculation notation – continued**

| | | | |
|---|---|---|---|
| Scope | | | |
| Ab | biofuel production asset | Cu | location of upstream production asset (country) |
| Ae | electricity generation asset | demand, supply | demand/supply for upstream production |
| Al | LNG asset | delivered | energy delivered from a given stage |
| Ag | GTL asset | elec | electric energy |
| Ar | Refinery asset | outturn | output from a refinery |
| Au | hydrocarbon producing asset (upstream) | plant,wind, solar | type of power generation technology |
| Cb | location of biofuel production asset (country) | prod_mix | multiple hydrocarbon types |
| Ce | location of electricity generation asset (country) | prod_gas | natural gas product type |
| Cl | location of LNG asset (country) | prod_oil | liquid hydrocarbon product type |
| Cg | location of GTL asset (country) | Re | location of electric market (variable regional granularity) |
| Cr | location of processing asset (country) | Rs | location of sales region |
| Product Transport | | | |
| d | unit distance | pipe | transportation via pipeline |
| mode | placeholder for mode of transportation | ship | transportation via ship |

### 2.2.3. Data Sources and Input Data Preparation

#### Conversion Factors

Input data sources do not always provide emissions and product volumes in the units required by the NCF methodology (i.e. $gCO_2e$ for emissions and $MJ_{LHV}$ for energy). Conversion factors are used to transform inputs into the required units, these factors are sourced from publicly available sources such as the America Petroleum Institute Compendium of Greenhouse Gas Emissions Methodologies for the Natural Gas and Oil Industry (API Compendium) [5].

#### Energy Product Volumes

Total energy product sales and Shell-equity production are a significant input to the NCI calculation. Facility production (outturn) and feedstock intake volumes (or associated plant efficiency metrics) for Shell assets are used in conjunction with energy product sales volumes to determine the balance of Shell-equity produced and 3rd party produced energy products sold by

Shell. Shell hydrocarbon production volumes are also used in the calculation of oil and gas production CIs.

Both sales and asset production volumes are sourced through Shell reporting channels and prepared for input into the NCI model. Volumetric data is converted to an energy equivalent, i.e. barrel of oil equivalent (boe) or megajoules lower heating value basis ($MJ_{LHV}$) either during input data preparation steps or internally by the NCI model.

Specific product property data (e.g. gas composition, hydrocarbon density, etc.) is not always available and assumptions have to be made regarding the energy content in the different product types to enable the conversion of volumes into energy; conversion factors are taken from sources such as the API compendium [5].

A global power efficiency factor ($PE_t$ ) is used to convert the electrical energy sold by Shell and the associated emissions intensities into a fossil-equivalence basis by

$$E_t = \frac{E_{elec,t}}{PE_t} \quad \text{(Eq. 05)}$$

and,

$$CI_t = CI_{elec,t} * PE_t \, . \quad \text{(Eq. 06)}$$

The $elec$ subscript on energy is used to indicate that the energy or intensity is represented in terms of electrical energy. Energy or intensity values from the power pathway without the subscript are fossil-fuel equivalents. $PE_t$ is ta time-variant power generation efficiency ratio relating the volume of electricity generated to the volume of primary energy input ($MJ_{elec}/MJ_{fuel}$).

## Emission Intensities

### Up-, Mid-, and Downstream Operations – Facility Specific

The carbon intensity of each stage in the energy lifecycle pathway is estimated during the NCI calculation. The intensity of upstream operations to produce raw hydrocarbons, mid-stream operations to process and transport products, and downstream operations to produce finished energy products are either calculated by the NCI model from primary data or taken as a secondary data input.

For assets ($A$) (up-, mid-, and downstream) with Shell-equity, operational emissions ($GHG$) and produced energy product ($E$) data are typically available through Shell reporting channels, such that the characteristic carbon intensity ($CI$) associated with facility operations can be calculated by

$$CI_{A,t} = \frac{\mathrm{GHG}_{A,t}}{E_{A,t}}. \quad \text{(Eq. 07)}$$

For hydrocarbon upstream production and subsequent processing operations (e.g. refineries, LNG, GTL), the calculation is straightforward once the product volumes are converted to energy content. The emission intensities for Shell power generation assets are converted to a fossil fuel equivalent value using the method described previously (Eq. 06).

The emissions and production data for 3rd party operations are not readily available in the public domain. As a result, emission intensity data for 3rd party operations (up-, mid-, and downstream) cannot be calculated directly as is the case for Shell production. In order of preference, 3rd party emission intensities are:

1. directly sourced from publicly available data sources,
2. calculated indirectly using publicly available sources, or,
3. are assumed to have the same average intensity as Shell-produced products on a regional basis, when publicly available data is unavailable.

Product Transport

The emission intensity associated with transporting feedstocks from upstream operations to mid- and downstream facilities, as well as the emission intensity for the distribution of processed products, is required to account for product consumption as fuel or lost as fugitive emissions. The emission intensity ($CI^{stage,pathway}$) associated with transporting a given product ($prod$) is calculated using emission factors that are a function of distance transported ($CI_{mode/d,prod}$), by

$$CI^{stage,pathway} = CI_{mode/d,product} * D^{stage,pathway}_{(loc\_start,loc\_end)} \quad \text{(Eq. 08)}$$

where $mode$ refers to the method of transportation (e.g. pipeline, ship) and $D$ is the distance of transportation.

The fraction of the energy product consumed as fuel or lost through fugitive emissions is calculated using a product reduction factor ($R_{mode/d,product}$) that is a function of distance transported, by

$$R^{stage,pathway} = R_{mode/d,product} * D^{stage,pathway}_{(loc\_start,loc\_end)} \quad \text{(Eq. 09)}$$

where $loc$ denotes the start and end locations of transport. These factors are also referred to as product loss factors or may be represented as operational efficiencies rather than product reductions or losses. The reduction factor terminology is used to allow more generic descriptions of the product pathways.

The emission and reduction factors used are sourced from lifecycle greenhouse gas emission modelling tools and published studies including[3]:

- *Greenhouse gases, Regulated Emissions, and Energy use in Transportation* (GREET) model from the Argonne National Laboratory, U.S. Department of Energy [7];
- GHGenius model by (S&T) Squared Consultants Inc. [8];
- *NETL Life Cycle Inventory Data – Unit Process: Natural Gas, Pipeline, Transport* data from the U.S. Department of Energy, National Energy Technology Laboratory [9]; and,
- Reports from the Joint Research Centre (JRC), EUCAR and Concawe collaboration (JEC) [10].

[3] This is not an exhaustive list, a selection of the most commonly used data sources is provided.

Production reduction/loss factors may also be sourced from Shell data. The distances used in the lifecycle analysis vary by principal pathway. Reasonable efforts are made to estimate the distances between export and import facilities and estimate local transportation distances.

End-Use

For hydrocarbon-based energy products, complete combustion is assumed (i.e. full carbon content of hydrocarbon product released) for calculating carbon dioxide emissions and energy content. Differences in end-use efficiency are not considered within the NCI calculation. Combustion emission factors are mainly sourced from the API compendium [5].

### 2.2.4. Upstream Production Allocation to Mid & Downstream Operations

Upstream production refers to the extraction of hydrocarbons from subsurface reservoirs and initial processing (if applicable) prior to transportation to refineries, liquefaction plants, etc. for further processing. During upstream operations, assets typically produce mixed hydrocarbon streams (e.g. crude oil, natural gas, condensate, natural gas liquids, etc.). Natural gas is assumed to be routed for use in LNG, GTL, and power generation facilities or delivered directly to customers via pipeline transportation (pipeline gas). Liquid hydrocarbons are assumed to be available as feedstock for Shell processing facilities (refineries). During the NCI calculation, the production and emissions attributed to upstream assets must be allocated appropriately across multiple production/processing assets within multiple principal pathways.

#### Upstream Production

Production volumes from Shell upstream assets are available by product type and asset. Volumes are converted into energy content ($\mathrm{E}$) to allow for the direct comparison of different product types. The volume of liquid hydrocarbon (crude oil) feedstock produced by a given upstream asset ($Au$) in country ($\mathrm{Cu}$) is represented by

$$E^{up}_{prod\_oil,Au,Cu,t} = \sum_{prod\_oil} E^{up}_{prod\_mix,Au,\mathrm{Cu},t}. \quad \text{(Eq. 10)}$$

where $prod\_mix$ denotes the hydrocarbon streams, $prod\_oil$ denotes the liquid hydrocarbon streams produced excluding natural gas, and $t$ denotes timeframe (year).

The volume of natural gas produced by a given upstream asset ($Au$) in country ($\mathrm{Cu}$) is

$$E^{up}_{prod\_gas,Au,Cu,t} = \sum_{prod\_gas} E^{up}_{prod\_mix,Au,\mathrm{Cu},t}. \quad \text{(Eq. 11)}$$

where $prod\_gas$ denotes the natural gas hydrocarbon stream(s).

Emission Intensity of Upstream Operations

The emission intensity of upstream operations ($CI^{up}_{Au,Cu,t}$) for a given upstream asset ($Au$) in country ($Cu$) is calculated by distributing the total operational emissions ($GHG^{up}_{Au,t}$) across all the hydrocarbon production streams ($E^{up}_{prod,Au,t}$). It is expressed as

$$CI^{up}_{Au,\mathrm{Cu},t} = \frac{GHG^{up}_{Au\ Cu,,t}}{\sum_{prod\_mix} E^{up}_{prod\_mix,Au,\mathrm{Cu},t}}. \quad \text{(Eq. 12)}$$

Emissions are proportionally allocated on an energy basis across the various product types.

The emission intensity is aggregated to a country level and used as input to the various principal pathway lifecycle intensity calculations. The country-average emission intensity of upstream production is

$$CI_{\mathrm{Cu},t}^{up} = \frac{\sum_{Au\_in\_Cu} GHG_{Au\;Cu,,t}^{up}}{\sum_{Au\_in\_Cu}\left(\sum_{prod\_mix} E_{prod\_mix,Au,\mathrm{Cu},t}^{up}\right)} \quad \text{(Eq. 13)}$$

where $Au$ denotes the upstream assets in country $Cu$.

Allocation of Upstream Production

The NCI calculation assumes that all upstream production, after accounting for product loss during transportation due to consumption as fuel and/or loss through fugitive emissions, is available as feedstock for mid- and downstream Shell assets. This ensures:

- the resulting NCI responds appropriately to any change in the emission intensity of Shell operations; and,
- the apportionment of oil and gas between Shell refineries or gas-processing facilities is automatic and pro rata with in-country feedstock demand.

Crude oil is allocated to Shell refineries and the crude oil supply and refinery demand (intake) are balanced on a country-by-country basis. The total feedstock supplied by Shell ($E_{Cu,t}^{up,oil}$) from each country is represented by

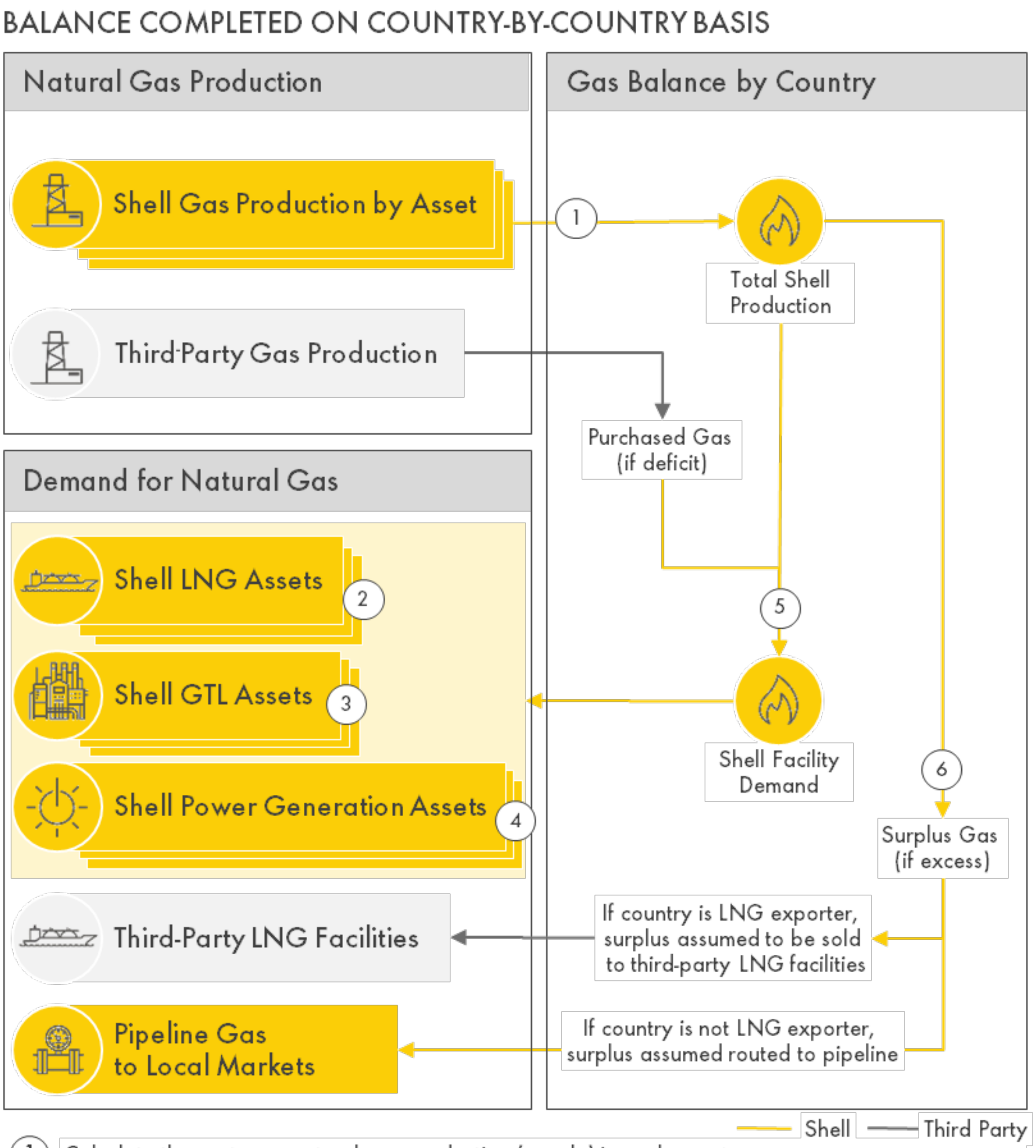
$$E_{Cu,t}^{up,oil} = \sum_{Au\_in\_Cu} E_{prod\_oil,Au,Cu,t}^{up} \quad \text{(Eq. 14)}$$

where $Au$ denotes the upstream assets in country $Cu$. The notation $oil$ denotes the energy is allocated as feedstock to the oil pathway. Product type is dropped from the notation as it is evident from the pathway indicator. More details on matching crude feedstock production with refinery demand are provided in Section 3.

Natural gas production is allocated for use as feedstock for Shell LNG or GTL assets, use as fuel in Shell electricity generation facilities, or routed to pipeline (pipeline gas). Shell production is allocated to different principal pathways on a country-by-country basis by the NCF model. The approach used to allocate natural gas production to facility demand is summarized in Figure 4.

Gas production is first allocated to Shell LNG, GTL or power (gas-fired) facilities. In cases where there is insufficient upstream gas production to satisfy in-country demand from Shell assets, the available volume is distributed pro-rata based on each facilities feed gas demands. If there is sufficient Shell-production to meet in-country facility demand, the surplus gas may be routed to pipeline for distribution to customers or is assumed to be allocated to 3rd party LNG production, depending on whether the country is defined as an LNG exporter within the model.

An overview of the gas production allocation calculation is provided in Appendix 2. The output is the gas supply by country ($Cu$) allocated to LNG, GTL, electricity generation, and routed to pipeline natural gas ($V_{supply,Cu,t}^{up,LNG}, V_{supply,Cu,t}^{up,GTL}, V_{supply,Cu,t}^{up,elec}, V_{supply,Cu,t}^{up,gas}$). These volumes are used as inputs to subsequent lifecycle analysis for the respective energy pathways.




1. Calculate the upstream natural gas production (supply) in each country.
2. Calculate the natural gas demand from all LNG facilities with Shell-equity in each country.
3. Calculate the natural gas demand by GTL facilities with Shell-equity in each country.
4. Calculate the natural gas demand by power generation (gas fired) facilities with Shell-equity in each country.
5. Allocate natural gas production to meet the demand from all facilities with Shell-equity and route any surplus. If there is insufficient natural gas to meeting in-county demand, the amount of natural gas is distributed pro-rata with the facilities gas demand. The deficit is made up from third-party gas.
6. Allocate natural gas production surplus to: 1) third-party LNG facilities if the country is designated a major LNG exporter, or 2) pipeline for distribute to end-users as part of the natural gas principal pathway if the country is not designated a major LNG exporter.

**Figure 4:** Schematic of approach used to allocate Shell natural gas production to Shell assets on a country-by-country basis

# 3. Oil Product Pathway

## 3.1. Lifecycle Pathway

The lifecycle analysis for the oil products pathway (Figure 5) includes the following stages:

1) **production** of crude oil by upstream assets;
2) **transportation** of crude oil via pipeline to local facilities (e.g. export terminal);
3) **export** of crude oil to processing facilities (refineries);
4) **processing** of crude oil into refined oil products;
5) **distribution** of refined oil products; and
6) **consumption** (combustion) of the oil products.

The emission intensity of the operational portion of the pathway is referred to as the "Well-to-Tank" (WtT) intensity and the lifecycle emission intensity including end use is referred to as the "Well-to-Wheel" (WtW) intensity. Each operation in Figure 5 is associated with a characteristic intensity that describes emissions from only that portion of the total WtT intensity. The WtT intensity is generalized as the summation of the characteristic intensity (Shell or 3rd party) for each stage in the oil product pathway.

$$CI^{WtT,oil} = CI^{up,oil} + CI^{local,oil} + CI^{exp,oil} + CI^{ref,oil} + CI^{dist,oil} \quad \text{(Eq. 15)}$$

This is a simplified representation of the actual calculation, in practice additional elements are included to account for the relative weighting of the characteristic intensities from Shell and 3rd party production at the "sales" stage of the pathway. The final WtW intensity is

$$CI^{WtW,oil} = CI^{WtT,oil} + CI^{end\_use,oil} \quad \text{(Eq. 16)}$$

where the characteristic intensity for end use is combustion.

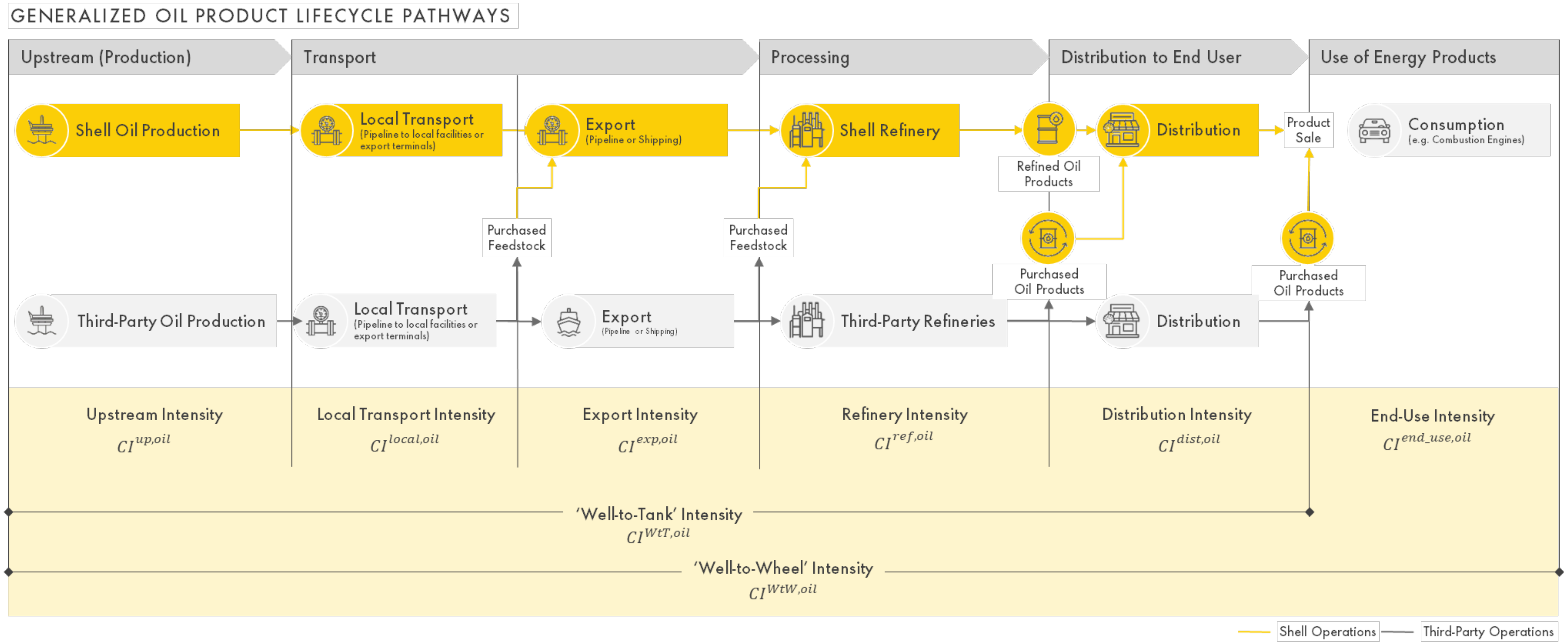



Figure 5: Schematic of the pathway for oil products.

Figure 5 demonstrates that there are multiple pathways for upstream crude oil production to supply downstream refineries. Each Shell refinery could be supplied by multiple Shell or 3rd party upstream sources. The WtT intensity calculated for any individual pathway will vary depending on the Shell- and 3rd party characteristic intensities included in the specific pathway from upstream production to the distribution of refined products.

In practice, the characteristic intensities for some stages such as export and distribution are calculated using assumptions common to both Shell- and 3rd party operations, which reduces the number of specific pathways necessary to model. The WtT intensity for Shell's full oil product portfolio is calculated by weighting the WtT intensities for each of the Shell-produced and 3rd party produced pathways using the fractional proportion of the total sales from each pathway.

## 3.2. Methodology

The calculation of the lifecycle intensity for oil products is driven by the total volume of oil products sold by Shell. Shell oil product sales on a regional basis are used as an input to the calculation. The regional split used is: 1) Africa, 2) America, 3) Asia, 4) Europe, 5) Oceania.

The WtT intensities for Shell-equity produced and 3rd party produced oil products are built up independently using the characteristic intensities for each stage in the oil product pathway (Figure 5). They are then aggregated by sales region. In each sales region, the volume of 3rd party product purchased and subsequently sold by Shell is calculated as the difference between the total sales and the Shell production in that sales region.

Characteristic intensities are calculated and input into the NCF calculation. The list of inputs includes:

- upstream production intensity by Shell asset;
- 3rd party upstream production intensity by country;
- export transportation intensity between various export and import countries;
- processing intensity by Shell refineries;
- 3rd party processing intensity by sales region, and,
- distribution intensity of refined products.

### 3.2.1. Shell Produced Oil Products

The WtT intensity of products produced by Shell refineries is assessed on an asset-by-asset basis assuming feedstock is supplied first by Shell-equity upstream production with the deficit made up by 3rd party production.

The general steps used to estimate the WtT intensity of Shell-produced products are summarized here. The first three steps are required to balance feedstock supply (Shell and 3rd party) and refinery demand country by country (Figure 6). The last two steps describe how the WtT intensity for each Shell refinery is estimated and subsequently aggregated by sales region.

**Step 1: Calculate the Shell-equity crude oil production and associated upstream intensity for all Shell upstream assets by country**

- The production and local pipeline transportation intensities are calculated for each Shell asset using asset-specific emissions and production data. The intensities and total feedstock production are then aggregated on a country-by-country basis to allow crude oil supply to be matched with refinery demand.

**Step 2: Calculate the crude oil demand (intake) from all Shell refineries by country**

- Each Shell refinery may source crude oil from multiple countries. The volume imported from a given country is calculated using refinery crude diets. Refinery diets define the fraction of feedstock imported from a country and used by a given refinery.
- The total crude oil demand from a given country is then calculated by summing the demand for crude oil from that country across all Shell refineries.

**Step 3: Balance the crude oil supply with Shell refinery demand by country**

- Crude oil supply and refinery demand is balanced on a country-by-country basis assuming that all Shell produced crude oil is used first and any deficit is made up from 3rd party production.
- The fractional split of Shell- and 3rd party crude oil production required to meet the total demand by country is calculated and subsequently used during the calculation of the weighted-average WtT intensity for each Shell refinery.

**Step 4: Calculate the WtT intensity for each Shell refinery**

- The WtT intensity for a given pathway including feedstock supply, refining and distribution is calculated by summing the individual intensities for each of the stages in the pathway (Figure 5)
- For each refinery, the country specific WtT intensity for Shell and 3rd party produced crude oil is calculated for each supply country. A weighted average of the country-specific intensities is then calculated to determine the overall WtT intensity for oil products produced by the refinery. Refinery diets are used to determine the proportion of crude oil supplied from each country. The fractional split of Shell and 3rd party produced crude oil by supply country is also used.

**Step 5: Calculate the total Shell refinery production and average WtT for each sales region**

- The WtT intensity for each Shell refinery is subsequently aggregated by sales region using a weighted average approach.

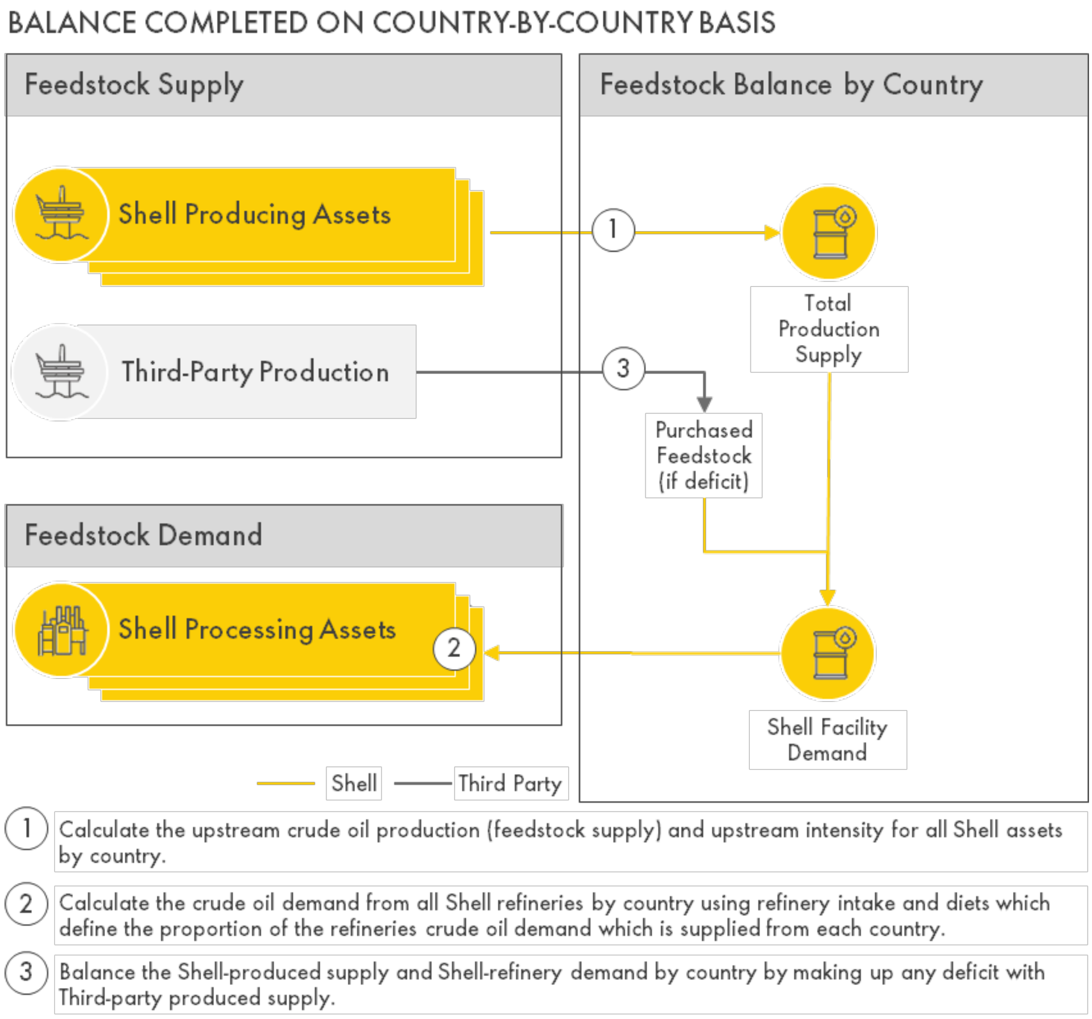



**Figure 6:** Schematic overview of the general steps used to balance feedstock supply and demand and calculate the country-average production intensity component of the WtT intensity for each refinery with Shell-equity.

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## 3.2.2. 3rd party Produced Oil Products

The lifecycle analysis for 3rd party produced oil products purchased by Shell for resale is estimated on a regional basis (sales region) instead of by asset.

First, country specific WtT intensities are calculated for each country supplying the sales region by summing:

- the average intensity of 3rd party crude production in a given supply country,
- the intensity for exporting crude oil from the supply country to the sales region;
- the average intensity of refining in the sales region, and
- the average intensity of distributing refined products

Second, the country specific WtT intensities are aggregated into the total WtT intensity for the sales region using a weighted average approach. As with the Shell produced case, refinery diets are used to determine the relative weights for the country specific WtT intensities for each crude oil producing country supplying the sales region.

Note that only 3rd party upstream intensities are used in this calculation as it is assumed that the feedstock supply is 100% non-Shell crude oil because:

- Shell-equity crude oil is preferentially allocated to Shell refineries;
- a clear line of sight from upstream production through processing facility to final sale is impossible to establish for 3rd party products purchased for resale.

### 3.2.3. Oil Energy Products by Sales Region

Once the WtT intensities for Shell-produced and 3rd party produced products are established by sales region, they are combined. For each sales region,

- The total volume of Shell-produced product is calculated by summing the production from each Shell refinery;
- The total volume of 3rd party produced product is calculated as the difference between total sales and Shell production; and,
- The total WtT intensity calculated as the weighted average of the Shell-produced WtT intensity and 3rd party WtT intensity for the sales region using the relative proportions of Shell-produced and 3rd party produced sales.

The lifecycle intensity (WtW) is then completed by adding the intensity associated with the combustion of oil products.

### 3.2.4. Shell's full Oil Products Portfolio

The WtW intensity of Shell's global oil products sales portfolio is finally calculated from the WtW intensities of each sales region using a weighted average approach. The total sales and sales by region are used to calculate the weights.

## 3.3. Input Data Sources & Preparation

Details of the data sources, assumptions, and preparation stages are presented here for each stage in the oil product pathway.

### 3.3.1. Shell Produced Oil products

#### Upstream Production & Local Transportation

Shell Production

Production data by product type and emissions from Shell upstream assets are sourced from Shell reporting channels and used to calculate emission intensity ($CI_{\mathrm{Cu},t}^{up}$) and crude oil production available as feedstock ($E_{Cu,t}^{up,oil}$) on a country basis.

The emission intensity associated with any local pipeline transport, e.g. between a production asset and an export terminal, is not included in the calculation as data on pipeline distances between Shell upstream assets and local facilities is not readily available. Sensitivity analysis demonstrates that omitting any local pipeline transport does not have a significant impact on Shell's overall portfolio NCI.

3rd party Production

The country-average emission intensity of 3rd party upstream production ($CI_{Cu,t}^{\overline{up},oil}$) is sourced from Masnadi et al. review of upstream emissions [11]. The emission intensities cover operational activities including: exploration, drilling and development, production and extraction, surface processing, and transport to local refinery facilities. Emissions associated with local transport via pipeline to local facilities (e.g. refinery or export terminal) are assumed to be included in the upstream intensity emissions and a separate CI is not calculated for local transportation.

Feedstock Export

The NCI model accounts for transporting crude oil by either pipeline or shipping. The characteristic intensity of exporting crude oil from upstream producers to Shell refineries ($CI_{(Cu,Cr)}^{exp,oil}$) is estimated using emission factors that are a function of distance transported as described in Section 2.2.3. The mode of transport and export distances ($D_{(Cu,Cr)}^{\mathrm{exp}\_(ship\ or\ pipe),oil}$) used are estimated from published data and input into the model.

Processing Facilities (Refineries)

Emissions, feedstock intake, and oil product outturn for refineries with Shell equity are sourced through Shell reporting channels. The feedstock intake and emissions are required to calculate the refinery intensity ($CI_{Ar,Cr,t}^{ref,oil}$), whilst the outturn is used to determine the refinery efficiency ($Eff_{Ar,Cr,t}^{ref,oil}$).

Outturn volumes from refineries are provided by product type (e.g. gasoline, kerosene, gas/diesel oils, fuel oils, LPG, etc.) in barrels. The fuel properties (e.g. density and energy content) associated with the volumes, however, are not readily available. Product volumes are converted into energy equivalents (boe) using product specific conversion factors obtained from the API compendium [5].

Commercially available crude slate data is used to estimate the fraction of the total crude oil demand that is imported from a supply country ($Cu$) to the refinery country ($Cr$) for use by a Shell refinery. This calculation uses refinery-specific feedstock supply data by country and is used to prepare the weighting factors ($W_{Ar,(Cu,Cr),t}^{import}$) input into the NCF model.

Distribution

The intensity for distribution ($CI^{dist,oil}$) of refined products is assumed to be a constant (time and asset independent) and is taken from publicly available data (e.g. JEC study [10]). The same distribution intensity assumption is used for Shell and 3rd party oil product sales.

### 3.3.2. 3rd Party Produced Oil Products

Upstream Production & Local Transportation

The same characteristic intensities for 3rd party upstream production $(CI_{Cu,t}^{\overline{up},oil})$ described previously for the Shell-produced case are used for the 3rd party produced case.

Feedstock Export

The same approach used for Shell-produced oil products is used to calculate the export intensity $(CI_{(Cu,Rs)}^{\overline{exp},oil})$ of 3rd party produced crude oil. The transportation mode (pipeline or shipping) and distance is estimated as described previously, except that a single destination country is chosen to determine representative shipping distances for each of the sales regions (Table 3).

Table 3: Representative countries by sales region

| Sales Region | Representative Country |
|---|---|
| Africa | South Africa |
| Americas | USA |
| Asia | China |
| Europe | Netherlands |
| Oceania | New Zealand |

Processing Facilities (Refineries)

The refinery intensities $(CI_{Rs,t}^{\overline{ref},oil})$ and efficiencies $(Eff_{Rs,t}^{\overline{ref},oil})$ for 3rd party refineries are calculated by sales region using commercially available refinery emission and intake data.

As with the Shell-produced case, commercially available crude slate data is used to estimate the fraction of crude oil supply by country that is imported for refining. However, instead of refinery specific calculations, the relative import weights $(W_{(Cu,Rs),t}^{\overline{import}})$ are calculated for supply country $(Cu)$ to sales region $(Rs)$ pairs using the representative countries for each sales region given in Table 3.

Distribution

The same intensity $(CI^{dist,oil})$ is used for distribution of 3rd party refined products as for Shell-refined products.

### 3.3.3. Product Sales

Sales volumes are sourced through Shell reporting channels. Biofuels and GTL volumes are removed from the total oil sales to prevent double counting. The emissions associated with these products are accounted for in the biofuels and GTL pathways.

Sales volumes are converted to energy equivalents $(E_{prod,Rs,t}^{sales,oil})$ and are aggregated into total oil product sales by region $(Rs)$. Only the sales of energy products are included i.e. gasoline, kerosene, gas/diesel oils, fuel oil, and LPG. Other products such as naphtha, bitumen, lubricants, and sulphur are treated either as intermediates/feedstocks or non-energy products and are not included.

### 3.3.4. End Use

The end use emission intensity ($CI_t^{end\_use,oil}$) for oil products is estimated by calculating a weighted average combustion emissions factor for the combustion of the different oil products (e.g. gasoline, kerosine, gas/diesel oil, fuel oil, and LPG) produced by Shell. The weighting is determined by the proportion of each product in Shell's refinery outturn.

The same end-use emission intensity is used for Shell and 3rd party produced products.

## 3.4. Calculation Overview

A description of the calculations and assumptions are provided for Shell-equity produced and 3rd party produced cases, working through the energy pathway from start to finish. This is followed by a description of how the Shell- and 3rd party produced lifecycle intensities are aggregated by sales regions and finally used to calculate the WtW intensity of all oil products sold by Shell.

### 3.4.1. Shell Produced Oil Products

#### Upstream Production

Shell-Equity Production

The total feedstock production ($E_{Cu,t}^{up,oil}$), and upstream emission intensity ($CI_{Cu,t}^{up,oil}$) is calculated in advance by country and used as an input to the NCI calculations. The average upstream intensity ($CI_{Cu,t}^{up,oil}$) for a country is calculated using a weighted average approach by

$$CI_{Cu,t}^{up,oil} = \sum_{Au\_in\_Cu} \left[ \left( CI_{Au,Cu,t}^{up} + CI_{Au,Cu,t}^{local,oil} \right) * W_{Au,Cu,t}^{up,oil} \right]. \quad \text{(Eq. 17)}$$

The upstream production intensity ($CI_{Au,Cu,t}^{up,oil}$) and the intensity for pipeline transport to local facilities ($CI_{Au,cu,t}^{local,oil}$) are combined as local pipeline transport can be considered part of upstream operations. $W_{Au,Cu,t}^{up,oil}$ is the fraction of Shell's total crude production ($E_{Cu,t}^{up}$) in the country that is contributed by the asset and is calculated by

$$W_{Au,Cu,t}^{up,oil} = \frac{E_{Au,Cu,t}^{up,oil}}{\sum_{Au\_in\_Cu} E_{Au,Cu,t}^{up,oil}} = \frac{E_{Au,Cu,t}^{up,oil}}{E_{Cu,t}^{up,oil}}. \quad \text{(Eq. 18)}$$

3rd Party Production

The characteristic emission intensity for 3rd party upstream production ($CI_{Cu,t}^{\overline{up},oil}$) by country [11] is input into the NCI calculations. The volume of feedstock supplied from 3rd party production is calculated by balancing feedstock supply and refinery demand (intake) country-by-country. It is calculated internally by the model when computing the weighted upstream intensities for each Shell refinery.

### Feedstock Transportation (Export)

The emission intensity of exporting crude oil feedstock from a producing country to a processing country is calculated assuming either pipeline ($pipe$) or shipping ($ship$) modes of transport. The intensity is estimated by

$$CI_{(Cu,Cr)}^{exp,oil} = CI_{(ship\ or\ pipe)/d,oil} * D_{(Cu,Cr)}^{\exp\_(ship\ or\ pipe),oil} \quad \text{(Eq. 19)}$$

where $Cu$ denotes the export location, $Cr$ denotes import location, and $D$ is the export distance. For both shipping and pipeline modes, the intensity is estimated from an intensity per distance of transport. The same approach to the export intensity calculation is used for Shell-produced and 3[rd] party produced crude oil.

### Processing Facilities (Refineries)

The intensity ($CI_{Ar,Cr,t}^{ref,oil}$), feedstock demand ($E_{Ar,Cr,t}^{ref,oil}$) and refinery efficiency ($Eff_{Ar,Cr,t}^{ref,oil}$) for each processing asset (refinery; $Ar$) are calculated in advance and used as inputs to the NCI calculation. It is important to note that the refinery intensity is calculated on an intake basis rather than an outturn basis. Accordingly, $CI_{Ar,Cr,t}^{ref,oil}$ is scaled by the refinery efficiency factor when the WtT intensity is calculated, this becomes more apparent in the subsequent description of the WtT intensity calculation.

The total refinery demand ($E_{Cr,t}^{ref,oil}$) for all refinery assets ($Ar$) with Shell-equity in country ($Cr$) is determined by

$$E_{Cr,t}^{ref,oil} = \sum_{Ar\_in\_Cr} E_{Ar,Cr,t}^{ref,oil}. \quad \text{(Eq. 20)}$$

The weighted average refinery intensity by country is

$$CI_{Cr,t}^{ref,oil} = \sum_{Ar\_in\_Cr} (CI_{Ar,Cr,t}^{ref,oil} * W_{Ar,Cr,t}^{ref,oil}). \quad \text{(Eq. 21)}$$

$W_{Ar,Cr,t}^{ref,oil}$ is the fraction of the feedstock demand in the country that is attributed to a given refinery and is calculated by

$$W_{Ar,Cr,t}^{ref,oil} = \frac{E_{Ar,Cr,t}^{ref,oil}}{\sum_{Ar\_in\_Cr} E_{Ar,Cr,t}^{ref,oil}} = \frac{E_{Ar,Cr,t}^{ref,oil}}{E_{Cr,t}^{ref,oil}}. \quad \text{(Eq. 22)}$$

Each refinery satisfies its feedstock demand by sourcing crude oil from multiple countries. To account for this in the NCF model, the crude oil demand from a given country ($Cu$) is calculated for each refinery by

$$E_{Ar,Cu,t}^{ref,oil} = E_{Ar,Cr,t}^{ref,oil} * W_{Ar,(Cu,Cr),t}^{import}. \quad \text{(Eq. 23)}$$

Supply country ($Cu$) is used to distinguish between the country where the crude oil is produced and the country ($Cr$) in which it is refined. $W_{Ar,(Cu,Cr),t}^{import}$ is the relative proportion of a refineries feedstock supply which is imported from a supply country ($Cu$) to the refinery country ($Cr$). This value is calculated in advance from refinery diet data and used as an input to the NCI calculation.

The total crude oil demand from a given supply country to meet the demand of all Shell refineries is

$$E_{Cu,t}^{ref,oil} = \sum_{Ar} E_{Ar,Cu,t}^{ref,oil}. \qquad \text{(Eq. 24)}$$

This is used to proportionally allocate the Shell upstream production from a supply country to all importing refineries. The fraction allocated to each refinery is given by

$$W_{Ar,Cu,t}^{ref,oil} = \frac{E_{Ar,Cu,t}^{ref,oil}}{E_{Cu,t}^{ref,oil}}. \qquad \text{(Eq. 25)}$$

where the refinery specific demand from a given supply country is divided by the total demand for crude oil from that country by all Shell refineries.

## Distribution

The constant intensity used for the distribution of refined products ($CI^{dist,oil}$) is input into the model.

## WtT Intensity by Refinery

The WtT intensity ($CI_{Ar,t}^{WtT,oil}$) for each refinery ($Ar$) is built up using the:

- Shell-produced feedstock supply ($E_{Cu,t}^{up,oil}$) by supply country;
- Shell-produced upstream intensity ($CI_{Cu,t}^{up,oil}$) by supply country;
- Demand from all Shell refineries ($E_{Cu,t}^{ref,oil}$) by supply country;
- 3rd party produced upstream intensity ($CI_{Cu,t}^{\overline{up},oil}$) by supply country; and,
- Intensity for transporting crude oil from each supply country to the refinery country ($CI_{(Cu,Cr)}^{exp,oil}$);
- Refinery efficiencies ($Eff_{Ar,Cr,t}^{ref,oil}$); and,
- distribution intensity for oil products ($CI^{dist,oil}$);

The following calculations are completed for each country exporting crude oil to a specific refinery:

- the ratio of the demand for Shell-produced to 3rd party produced supply is

$$Shell\_Share_{Cu,t}^{ref,oil} = min\left[1, \frac{E_{Cu,t}^{up,oil}}{E_{Cu,t}^{ref,oil}}\right]. \qquad \text{(Eq. 26)}$$

- the WtT intensity for the Shell produced supply processed by the specific refinery is

$$CI_{Ar,Cr,t}^{WtT,oil} = (CI_{Cu,t}^{up,oil} + CI_{(Cu,Cr)}^{exp,oil} + CI_{Ar,Cr,t}^{ref,oil}) * Eff_{Ar,Cr,t}^{ref,oil} + CI^{dist,oil} \qquad \text{(Eq. 27)}$$

- the WtT intensity for the 3rd party produced supply processed by the specific refinery is

$$CI_{Ar,Cr,t}^{\overline{WtT},oil} = (CI_{Cu,t}^{\overline{up},oil} + CI_{(Cu,Cr)}^{exp} + CI_{Ar,Cr,t}^{ref,oil}) * Eff_{Ar,Cr,t}^{ref,oil} + CI^{dist,oil} \qquad \text{(Eq. 28)}$$

The total WtT intensity including all countries supplying the refinery is then calculated by summing the Shell-supplied and 3rd party intensities for all importing countries with the appropriate weightings,

$$CI_{Ar,Cu,t}^{WtT,oil} = \sum_{Cu}\Big[\big(CI_{Ar,Cu,t}^{WtT,oil} * W_{Ar,(Cu,Cr),t}^{import} * Shell\_Share_{Cu,t}^{ref,oil}\big) + \big(CI_{Ar,Cu,t}^{\overline{WtT},oil} * W_{Ar,(Cu,Cr),t}^{import} * \big(1 - Shell\_Share_{Cu,t}^{ref,oil}\big)\big)\Big].$$

(Eq. 29)

The accent on $WtT$ is removed as no differentiation is made between products notionally refined from Shell-produced crude oil and those refined from crude oil produced by 3rd parties.

This approach addresses multiple feedstock supply-demand scenarios including where:

- there is no Shell-equity production in a supply country supplying a specific Shell refinery. In this case, the Shell_Share weighting becomes zero and $CI_{Ar,Cu,t}^{WtT,oil}$ does not contribute to the total refinery intensity.
- there may be more Shell-equity production in a supply country than required by Shell refineries. In this case, the weighting of $CI_{Ar,Cu,t}^{\overline{WtT},oil}$ becomes zero and only $CI_{Ar,Cu,t}^{WtT,oil}$ contributes to the total refinery intensity. Any surplus Shell-equity production is left unused.
- there may not be enough Shell-equity production in a supply country to meet the demand of Shell refineries. In this case, the demand deficit is made up of from 3rd production and a weighted upstream intensity is calculated.
- there may be Shell-equity or 3rd party production in a given country, but the production is not used as feedstock for a specific refinery. In this case the weighting for the country $W_{Ar,(Cu,Cr),t}^{import}$ is zero and the supply country does not contribute to the total refinery intensity

### WtT Intensity by Sales Region

For each sales region ($Rs$), the total volume of Shell-produced product ($E_{outurn,Rs,t}^{ref,oil}$) is calculated by summing the production from each Shell refinery ($Ar$) in the sales region:

$$E_{outurn,Rs,t}^{ref,oil} = \sum_{Ar\_in\_Rs} \frac{E_{Ar,Cr,t}^{ref,oil}}{Eff_{Ar,Cr,t}^{ref,oil}} \qquad \text{(Eq. 30)}$$

where Shell production is estimated from the feedstock demand ($E_{Ar,Cr,t}^{ref,oil}$) and refinery efficiency ($Eff_{Ar,Cr,t}^{ref,oil}$). It is assumed that none of the refined product is consumed during distribution and the total amount of Shell-refined product available to sell to customers is the same as the amount produced ($E_{outurn,Rs,t}^{ref,oil} = E_{outurn,Rs,t}^{end\_use,oil}$).

The associated weighted average WtT intensity of Shell-produced product is calculated by

$$CI_{Rs,t}^{WtT,oil} = \frac{\sum_{Ar\_in\_Rs}\left(CI_{Ar,Cr,t}^{WtT,oil} * E_{Ar,Cr,t}^{ref,oil} \Big/ Eff_{Ar,Cr,t}^{ref,oil}\right)}{E_{outurn,Rs,t}^{ref,oil}} \qquad \text{(Eq. 31)}$$

## 3.4.2. 3rd party Produced Oil Products

The WtT intensity of 3rd party produced oil energy products purchased for resale by Shell are assessed by sales region (Rs).

### Upstream Production & Local Transportation

The same characteristic intensities for 3rd party upstream production ($CI_{Cu,t}^{\overline{up},oil}$) by country used for Shell-produced case are used for computing the lifecycle intensity of 3rd party production.

### Export

The same approach (Eq 19) used for the Shell-produced case described previously is used to calculate the export intensity ($CI_{(Cu,Rs),t}^{\overline{exp},oil}$) of 3rd party produced feedstock.

### Processing Facilities (Refineries)

The refinery intensity ($CI_{Rs,t}^{\overline{ref},oil}$) and efficiency ($Eff_{Rs,t}^{\overline{ref},oil}$) for 3rd party refineries are calculated by sales region using commercially available refinery emission and intake data. They are calculated in advance and used as inputs to the NCF calculation.

### Distribution

The same intensity ($CI^{dist,oil}$) is used for distribution of 3rd party refined products as Shell-refined products.

### WtT Intensity by Sales Region

Crude oil is imported from multiple countries to be refined by refineries in each sales region. The WtT intensity ($CI_{Cu,Rr,t}^{\overline{WtT},oil}$) for each crude oil source country ($Cu$) and refinery sales region ($Rs$) is calculated by

$$CI_{Cu,Rs,t}^{\overline{WtT},oil} = (CI_{Cu,t}^{\overline{up},oil} + CI_{Cu,t}^{\overline{local},oil} + CI_{(Cu,Rs),t}^{\overline{exp},oil} + CI_{Rs,t}^{\overline{ref},oil}\Big) * Eff_{Rs,t}^{\overline{ref},oil} + CI^{dist,oil}. \qquad \text{(Eq. 32)}$$

using the regional refinery intensity and efficiencies.

The total WtT intensity for each sales region is the weighted average of the individual $CI_{(Cu,Rs),t}^{\overline{WtT},oil}$ intensities. It is calculated by

$$CI_{Rs,t}^{\overline{WtT},oil} = \sum_{Cu}\Big(CI_{Cu,Rs,t}^{\overline{WtT},oil} * W_{(Cu,Rs),t}^{\overline{import}}\Big). \qquad \text{(Eq. 33)}$$

where $W_{(Cu,Rs),t}^{\overline{import}}$ is the fraction of the crude oil sourced from country ($Cu$) imported to the sales region ($Rs$).

## 3.4.3. Total Oil Products by Sales Region

For each sales region ($Rr$), the WtW intensity is calculated by combining the Shell-produced and 3rd party produced WtT intensities previously calculated. The volume of 3rd party produced sales ($E_{Rs,t}^{\overline{end\_use},oil}$) is estimated by

$$E_{Rs,t}^{\overline{end\_use},oil} = E_{Rs,t}^{sales,oil} - E_{Rs,t}^{end\_use,oil}. \qquad \text{(Eq. 34)}$$

where $E_{Rs,t}^{sales,oil}$ denotes the total volume of Shell's oil product sales and $E_{Rs,t}^{end\_use,oil}$ denotes the total volume of Shell-produced product in the sales region. It is assumed that all products produced by Shell are sold by Shell and any shortfall is made up from 3rd party products purchased for resale.

The weighted average WtT intensity for the sales region ($CI_{total,Rs,t}^{WtT,oil}$) is then

$$CI_{total,Rs,t}^{WtT,oil} = \frac{\left(CI_{Rs,t}^{WtT,oil} * E_{Rs,t}^{end\_use,oil}\right) + \left(CI_{Rr,t}^{\overline{WtT},oil} * E_{Rs,t}^{\overline{end\_use},oil}\right)}{\left(E_{Rs,t}^{end\_use,oil} + E_{Rs,t}^{\overline{end\_use},oil}\right)}. \qquad \text{(Eq. 35)}$$

The lifecycle intensity (WtW) for is then completed for the sales region by adding in the intensity associated with the use of the product ($\mathrm{CI}_{t}^{end\_use,\mathrm{oil}}$),

$$CI_{Rs,t}^{WtW,oil} = \mathrm{CI}_{\mathrm{total,Rs,t}}^{\mathrm{WtT}\ \ ,\mathrm{oil}} + \mathrm{CI}_{t}^{end\_use,\mathrm{oil}}. \qquad \text{(Eq. 36)}$$

where $CI_{t}^{end\_use,oil}$ is the average combustion intensity calculated for oil products.

### 3.4.4. Shell's Total Oil Products Portfolio

Finally, the WtW intensity of Shell's oil energy products sales portfolio is calculated from the WtW intensities of each sales region. It is the weighted average of all the regional groups, as shown by

$$CI_{port,t}^{WtW,oil} = \frac{\sum_{Rs}\left(E_{Rs,t}^{sales,oil} * CI_{Rs,t}^{WtW,oil}\right)}{\sum_{Rs} E_{Rs,t}^{sales,oil}}. \qquad \text{(Eq. 37)}$$

The total volume of oil products, on an energy basis, sold by Shell is

$$E_{port,t}^{end\_use,oil} = \sum_{Rs} E_{Rs,t}^{sales,oil}. \qquad \text{(Eq. 38)}$$

# 4. Natural Gas Pathway

## 4.1. Lifecycle Pathway

The lifecycle analysis for the natural gas pathway (Figure 7) includes the following stages:

1) **production & processing** of natural gas by upstream assets;
2) **transportation** of natural gas via a pipeline to customers; and,
3) **consumption** (combustion) of the natural gas.

Natural gas (gas) is produced during upstream production operations in many different countries. In continental locations, gas is transported by pipeline to customers or to temporary underground storage. In maritime locations, gas may be liquified and exported in the form of liquefied natural gas. Gas produced and transported directly via pipeline to customers is referred to as 'pipeline gas' in the NCF methodology. The lifecycle emissions of all pipeline gas sold by Shell are captured in the analysis of the natural gas pathway.

Pipeline gas sales exclude any gas used as fuel in Shell's operations or gas routed for further processing by Shell (such as liquefaction). The emissions associated with the natural gas used by Shell operations are included in other energy product pathways, e.g. as part of the LNG portfolio (Section 5), the GTL portfolio (Section 6), or the Electric portfolio (Section 8).

For convenience, the same nomenclature as the oil portfolio is used with the operational portion of the pathway being referred to as the "Well-to-Tank" (WtT) and the lifecycle carbon intensity including end use being referred to as "Well-to-Wheel" (WtW). In this case the WtT intensity is the combination of upstream and pipeline distribution intensities, and the full lifecycle intensity is calculated by adding the intensity of end-use.

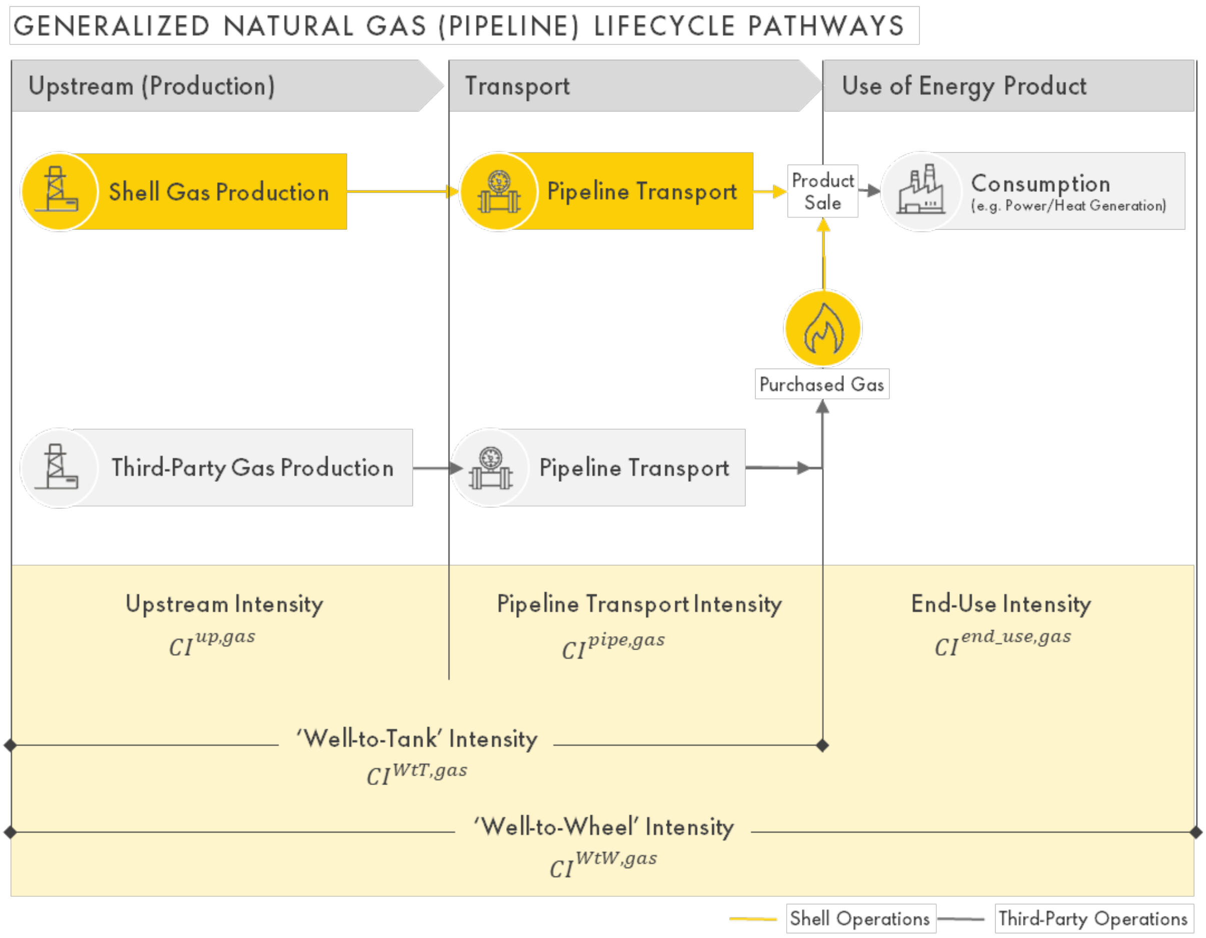


**Figure 7:** Schematic of the pathway for pipeline natural gas.

## 4.2. Methodology

The lifecycle intensity for pipeline gas is driven by: 1) the volume of Shell-produced natural gas routed to pipeline, and 2) the 3rd party produced gas purchased and subsequentially resold as pipeline gas.

The WtW intensities for Shell-equity produced and 3rd party produced gas sold to customers are established independently and subsequently aggregated on a weighted basis to calculate the total intensity of Shell's pipeline gas sales.

### 4.2.1. Shell Produced Pipeline Gas

For Shell-produced natural gas routed to pipeline, the lifecycle pathway is analysed on a country-by-country basis. The general steps used to calculate the lifecycle intensity are summarized here.

Step 1: **Calculate the volume of Shell-produced natural gas sold as pipeline gas per country**

- The volume of Shell-equity natural gas production routed to pipeline by country is determined using the approach outlined previously in Section 2.2.4. The volume allocated to pipeline gas is then adjusted to account for consumption and loss as fugitive emissions during pipeline transport.

**Step 2: Establish the emission intensity associated with the production of Shell-produced natural gas by country**

- The country average upstream intensity associated with Shell's natural gas production is determined using the approach outlined previously in Section 2.2.4 and used as an input to the calculation.

**Step 3: Calculate the intensity of transporting natural gas via pipeline by country.**

- The emission intensity associated with pipeline transport is estimated using the average distance for pipeline distribution in the country multiplied by a pipeline emissions factor.

**Step 4: Calculate the WtT intensity by country**

- The WtT emission intensity is the sum of the country average upstream intensity and intensity of gas distribution via pipeline.

**Step 5: Calculate the WtW intensity by country**

- The WtW emission intensity is calculated by adding the end-use intensity to the WtT intensity.

### 4.2.2. 3rd Party Pipeline Gas

For pipeline gas produced by 3rd parties, the lifecycle pathway is analysed based on the country or region in which the sale is reported.

**Step 1: Determine the volume of 3rd party produced natural gas by country or region of sale**

- Reported sales volumes by country or region only include gas produced by 3rd parties to avoid double counting.

**Step 2: Establish the WtT intensity for 3rd party natural gas production by country or region**

- The country average intensity of pipeline gas is used where data is available (e.g. GREET in the U.S. [7] or GaBi for Europe [12]). Where country or regional data is not available the intensity from another country or region may be used as a proxy.

**Step 3: Calculate the WtW intensity by country or region**

- The WtW emission intensity for 3rd party pipeline gas is completed by adding the end-use intensity to the WtT intensity for 3rd party produced pipeline gas.

### 4.2.3. Shell's Total Pipeline Gas Portfolio

The WtW intensity for Shell's total pipeline gas portfolio is then calculated by aggregating the intensities for all Shell-produced and 3rd party produced pipeline gas as a weighted average.

## 4.3. Input Data Sources and Preparation

Volumes and characteristic emission intensities for gas production are calculated separately and used as an input to the pipeline gas intensity calculation. The list of inputs includes:

- Shell-equity upstream production allocated to pipeline gas;
- Sales of 3rd party produced pipeline gas by country or region;

- intensity of natural gas production from assets with Shell-equity by country;
- WtT intensity for 3rd party production by country or region;
- intensity of pipeline transportation;
- average distance for pipeline distribution by country; and,
- end-use intensity.

## 4.3.1. Shell-produced Pipeline Gas

### Upstream Production

Section 2.2.4 provides an overview of how upstream emission intensities ($CI_{Cu,t}^{up}$) and the volume of Shell-produced natural gas ($V_{Cu,t}^{up,gas}$) routed to pipeline are calculated for each country.

The volumes are converted into their LHV energy content ($E_{Cu,t}^{up,gas}$) assuming all the natural gas produced has the same energy content. The values used for the volume-to-energy conversion are taken from the API compendium [6].

### Pipeline Transportation

The intensity of pipeline transport is calculated using a pipeline emissions factor ($CI_{pipe/d,gas}$) and estimated pipeline distance. The pipeline emission factor is estimated using NETL life cycle inventory data [9]. Pipeline length ($D_{Cu}^{pipe,gas}$) between upstream production and the point of end-use is estimated by country.

During pipeline transport, natural gas volumes are reduced by:

- consumption as fuel for pipeline operations (e.g. compression equipment); and,
- by fugitive emissions.

The volume reduction is estimated to allow the conversion of upstream production volumes to final sales volumes. The gas reduction factor ($GR_{pipe/d,gas}$) describes the natural gas volume reduction per unit of pipeline length.

Both pipeline emission and gas loss factors are assumed to be constant over time and geography.

## 4.3.2. 3rd party Produced Pipeline Gas

### Sales Volumes

Sales of natural gas produced by 3rd parties are sourced from Shell's reporting channels and are reported on a country or regional basis depending on the business segment. The volumes provided are converted into their LHV energy content ($E_{Rs,t}^{\overline{sales},gas}$) assuming all the natural gas has the same energy content.

### WtT Intensity

The WtT intensities of 3rd party produced gas purchased for resale are taken from various publicly or commercially available sources:

- Canada: GHGenius [13].
- USA: a weighted average of the WtT intensity for local natural gas production and the WtT intensity for imported pipeline natural gas. The upstream intensity of local gas production is sourced from GREET [7]. The intensity of local pipeline transport is estimated from pipeline length and the same pipeline emissions factors used to estimate the intensity of pipeline transmission for Shell produced gas. The local pipeline length is sourced from an NETL lifecycle analysis study [15]. The WtT intensity for local natural gas production is the sum of the local upstream and local transmission intensities. The WtT intensity of the imported pipeline natural gas is the same as that for Canada, assuming that gas is primarily sourced from Canada. The ratio of local to imported pipeline gas is determined from EIA natural gas production data [16].
- Mexico, Brazil: assumed to be the same as the USA
- Europe: GaBI Professional [12]
- Africa: assumed to be the same as Europe
- Australia: National Greenhouse Gas Accounts factors [17]

### 4.3.3. End Use

The end-use of pipeline natural gas ($CI_t^{end\_use,gas}$) is assumed to be combustion (e.g. during power or heat generation). The emission intensity is calculated from the carbon content[4] and energy content (LHV) of natural gas. Complete combustion of natural gas is assumed since it is not possible to apply a technology specific emissions factor given the diversity of possible end-uses.

## 4.4. Calculation Overview

### 4.4.1. Shell-produced Pipeline Gas

The volume of Shell-produced natural gas routed to pipeline ($E_{Cu,t}^{up,gas}$) per country is determined as per the upstream production allocation procedure (Section 2.2.4).

The WtT intensity is calculated on a country-by-country basis. The country average intensity ($CI_{\mathrm{Cu},t}^{up}$) used as an input to the NCF model is

$$CI_{Cu,t}^{up,gas} = \sum_{\mathrm{Au\_in\_Cu}}\left[\mathrm{CI}_{Au,Cu,t}^{up} * W_{Au,Cu,t}^{up,gas}\right]. \qquad \text{(Eq. 39)}$$

The emission intensity associated with the distribution of natural gas by pipeline is estimated by

$$CI_{Cu}^{pipe,gas} = CI_{pipe/d,gas} * D_{Cu}^{pipe,gas} \qquad \text{(Eq. 40)}$$

where $D_{Cu}^{pipe,gas}$ is the country average length of pipeline and $CI_{pipe/d,gas}$is the pipeline intensity for transporting natural gas per unit length of pipeline.

The WtT intensity is then calculated by

4 Carbon content of natural assumed to be 76% by wt., as per API compendium [5].

$$CI_{Cu,t}^{WtT,gas} = CI_{Cu,t}^{up} * \left(1 + GR_{pipe/d,gas} * D_{Cu}^{pipe,gas}\right) + CI_{Cu}^{pipe,gas} \qquad \text{(Eq. 41)}$$

where $GR_{pipe/d,gas}$ is the gas reduction per unit distance due to consumption as fuel or loss as fugitive emissions during pipeline transportation.

The WtW emission intensity is then calculated by

$$CI_{Cu,t}^{WtW,gas} = CI_{Cu,t}^{WtT,gas} + CI_{t}^{end\_use,gas} \qquad \text{(Eq. 42)}$$

where the end-use is the combustion of natural gas. The volume of pipeline gas delivered in a country is adjusted by

$$E_{Cu,t}^{end\_use,gas} = \frac{E_{Cu,t}^{up,gas}}{\left(1+GR_{pipe/d,gas}*D_{Cu}^{pipe,gas}\right)} \qquad \text{(Eq. 43)}$$

to account for consumption and losses during transportation via pipeline. The energy is considered representative of the sales stage in the pipeline gas lifecycle pathway.

The total WtW intensity for all Shell-produced pipeline gas sold to customers is

$$CI_{t}^{WtW,gas} = \frac{\sum_{Cu}\left[CI_{Cu,t}^{WtW,gas} * E_{Cu,t}^{end\_use,gas}\right]}{\sum_{Cu} E_{Cu,t}^{end\_use,gas}}. \qquad \text{(Eq. 44)}$$

### 4.4.2. 3rd party Produced Pipeline Gas

The amount of 3rd party-produced natural gas is obtained from the country or regional sales data. ($E_{Rs,t}^{\overline{sales},gas}$) and input into calculation.

For each sales country or region ($Rs$), the WtT intensity ($CI_{Rs,t}^{\overline{WtT},gas}$) is calculated separately using publicly or commercially available data, as described in Section 3.3.2. It is used to calculate the WtW emission intensity by

$$CI_{Au,Cu,t}^{\overline{WtW},gas} = CI_{Cu,t}^{\overline{WtT},gas} + CI_{t}^{end\_use,gas} \qquad \text{(Eq. 45)}$$

The total WtW intensity for all sales of pipeline gas produced by 3rd parties is then

$$CI_{t}^{\overline{WtW},gas} = \frac{\sum_{Rs}\left[CI_{Rs,t}^{\overline{WtW},gas} * E_{Rs,t}^{\overline{sales},gas}\right]}{\sum_{Rs} E_{Rs,t}^{\overline{sales},gas}}. \qquad \text{(Eq. 46)}$$

### 4.4.3. Shell's Total Pipeline Gas Portfolio

Shell's total pipeline gas sales intensities are calculated by

$$CI_{port,t}^{WtT,gas} = \frac{\sum_{Cu}\left[CI_{Cu,t}^{WtT,gas} * E_{Cu,t}^{end\_use,gas}\right] + \sum_{Rs}\left[CI_{Rs,t}^{\overline{WtT},gas} * E_{Rs,t}^{\overline{sales},gas}\right]}{\sum_{Cu} E_{Cu,t}^{end\_use,gas} + \sum_{Rs} E_{Rs,t}^{\overline{sales},gas}} \qquad \text{(Eq. 47)}$$

and

$$CI_{port,t}^{WtW,gas} = \frac{\sum_{Cu}\left[CI_{Cu,t}^{WtW,gas} * E_{Cu,t}^{end\_use,gas}\right] + \sum_{Rs}\left[CI_{Rs,t}^{\overline{WtW},gas} * E_{Rs,t}^{\overline{sales},gas}\right]}{\sum_{Cu} E_{Cu,t}^{end\_use,gas} + \sum_{Rs} E_{Rs,t}^{\overline{sales},gas}}. \qquad \text{(Eq. 48)}$$

The total energy delivered to customers is

$$E_{port,t}^{end\_use,gas} = \sum_{Cu} E_{Cu,t}^{end\_use,gas} + \sum_{Rs} E_{Rs,t}^{\overline{sales},gas}. \qquad \text{(Eq. 49)}$$

# 5. Liquified Natural Gas Pathway

## 5.1. Lifecycle Pathway

The lifecycle analysis for the liquefied natural gas (LNG) pathway (Figure 8) includes the following stages:

1) **production & processing** of natural gas by upstream assets;
2) **transportation** of natural gas via a pipeline to liquefaction plants;
3) **liquefaction** of natural gas;
4) **export** of LNG by ships;
5) **regasification** of LNG;
6) **distribution** of natural gas via pipeline to customers; and,
7) **consumption** (combustion) of the natural gas.

The emission intensity associated with LNG production, from natural gas production up-to and including liquefaction, is generally referred to as the "Well-to-Loading Arm" (WtLA). For convenience, the same nomenclature as the oil portfolio is used with the operational portion of the pathway being referred to as the "Well-to-Tank" (WtT) and the lifecycle carbon intensity including end use being referred to as "Well-to-Wheel" (WtW). In the context of the LNG pathway the WtT intensity is equivalent to the WtLA intensity plus the intensity of shipping, regasification and any subsequent pipeline distribution.

## 5.2. Methodology

Two distinct LNG production pathways can be modelled in the NCI calculation (Figure 8): 1) natural gas processed in Shell-equity liquefaction plants, and 2) natural gas processed in 3$^{rd}$ party liquefaction plants. Ideally the WtW emission intensities for these two pathways would be calculated independently and subsequently aggregated to the portfolio level. However, due to a lack of data on the emissions performance of 3$^{rd}$ party liquefaction plants it is not possible to independently model the lifecycle emission intensity for 3$^{rd}$ party produced LNG. As a result, it is assumed that 3$^{rd}$ party LNG purchased for resale is produced with the same intensity as the global average of Shell LNG production.

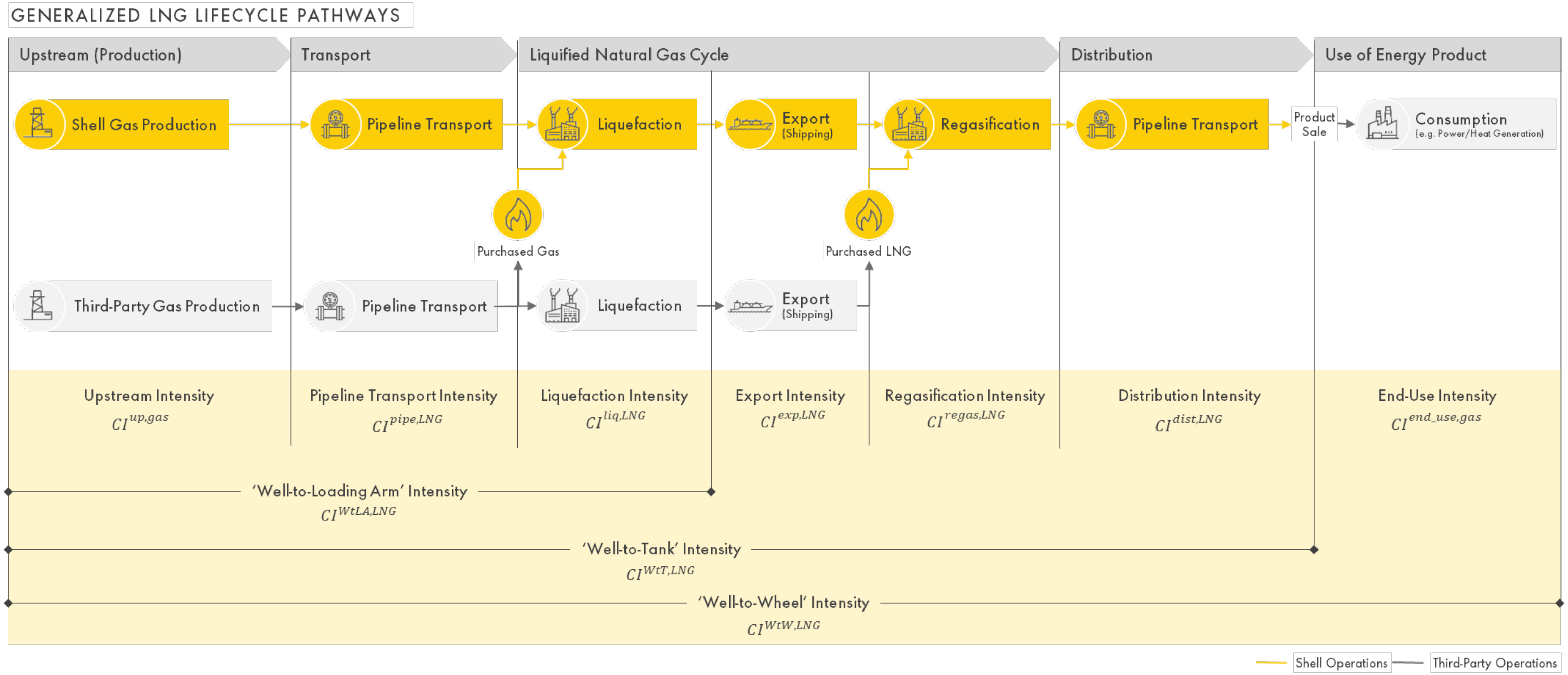


**Figure 8:** Schematic of the pathway for LNG

### 5.2.1. Shell Produced LNG

The general steps used to calculate the WtT intensity of Shell's LNG supply chain are summarized as:

**Step 1: Calculate the Shell-produced natural gas upstream intensity and supply allocated to LNG production by country**

- The upstream intensity and volume of Shell-produced natural gas allocated as LNG feedstock in each country is estimated as per the upstream production allocation approach outlined in Section 2.2.4. The supply allocation and upstream intensity are provided on a country-by-country basis.
- Integrated assets are treated differently since they report their complete operational emissions, including upstream production, and therefore the separate stages are not broken out (i.e. upstream production, pipeline transport, and liquefaction).

**Step 2: Balance the natural gas supply and demand from liquefaction plants by country**

- Natural gas demand by Shell liquefaction plants is calculated by country from LNG production and gas consumption data. Demand from integrated assets is excluded from the calculation.
- Demand for each LNG producing country is balanced by assuming that all Shell-produced gas is used first with any deficits being filled by 3rd party production. The fractional split between the Shell and 3rd party produced gas supply is computed and subsequently used when calculating the WtT intensity for each Shell asset.

**Step 3: Calculate the upstream intensity for each LNG producing country**

- The upstream intensity for a given LNG producing country is calculated using the supply fractional split and intensity of the different gas supplies (e.g. designated, Shell-produced, and 3rd party).
- In practice, data is not available for the intensity of gas production by 3rd parties and Shell's own gas production intensity in that country is used as a proxy.

**Step 4: Calculate the emission intensity of transporting natural gas from upstream assets to LNG producing countries**

- Generalized emission and consumption factors by distance of transport are used to calculate the pipeline transport intensity. Pipeline length is estimated separately and used as an input to the calculation.

**Step 5: Calculate the intensity and natural gas consumption ratios for LNG processing for each LNG producing country.**

- The emission intensity of LNG processing is calculated from emission and production data for each LNG producing country. The fraction of gas consumed during the process is also estimated for use in a subsequent stage of the calculation.

**Step 6: Calculate the 'Well-to-Loading Arm' (WtLA) intensity for each LNG producing country**

- The WtLA intensity is calculated by summing the previously calculated weighted average upstream intensity, the pipeline transport intensity, the liquefaction intensity, and gas losses.
- In the case of integrated LNG projects, the WtLA intensity is calculated as an asset intensity which is inclusive of upstream production and pipeline transport.

**Step 7: Calculate the emission intensity for LNG transport**

- The emission intensity associated with LNG shipping can vary by asset depending on the assumptions used for the export-import locations. Fleet specific emission and consumption factors by distance of shipping are used in the calculation. The shipping distance assumed for a given LNG asset is estimated by weighting the export-import distances for the various export-import pathways by the fraction of total LNG production delivered to each import destination.

**Step 8: Calculate the emission intensity for LNG regasification and subsequent natural gas distribution.**

- Generalized emission intensity factors and fuel consumption factors are used for regasification and distributing gas via pipeline. They are calculated separately and used as an input to subsequent calculations.

**Step 9: Calculate the WtT intensity for each LNG producing country**

- For each Shell liquefaction plant, the WtT intensity is calculated by summing the WtLA intensity and the emission intensities for shipping, regasification, and pipeline distribution.

**Step 10: Calculate the WtW intensity for each LNG producing country**

- The WtW intensity is calculated by adding the intensity of end-use, which is assumed to be combustion.

**Step 11: Calculate the average WtW CI for the global Shell-produced LNG supply chain.**

- The portfolio level WtW intensity is calculated by aggregating the WtW intensity for each asset, weighted by the relative fraction of total LNG production.

As noted above, integrated LNG projects are handled differently from other Shell LNG facilities because the operational emissions associated with integrated assets are reported as a whole and not broken down by stages (i.e. upstream production, pipeline transport, and liquefaction). Steps 4-6 are combined into a single step to directly calculate the WtLA intensity.

### 5.2.2. 3rd party Produced LNG

The difference between Shell's reported global LNG sales volume and Shell equity LNG production is assumed to be made up from LNG produced by 3rd parties:

**Step 1: Estimate the total volume of 3rd party produced LNG**

- Shell's equity LNG production is deducted from Shell's global LNG sales to give the total volume of 3rd party produced LNG sold by Shell.

**Step 2: Estimate losses due to regassification and distribution**

- The total volume of LNG produced by 3rd parties estimated in the previous step is assumed to be on an ex-ship basis, this volume is adjusted to account for losses during regasification and pipeline distribution to represent the final volume of natural gas delivered to customers.

3rd party produced LNG is assumed to have the same WtW intensity as the global average of Shell-produced LNG.

### 5.2.3. Shell's Total LNG Portfolio

Since it is assumed that 3rd party produced LNG has the same intensity as the global average of Shell-produced LNG, the lifecycle emission intensity of all LNG sold by Shell (Shell and 3rd party produced) is equivalent to that of Shell produced LNG.

## 5.3. Input Data Sources and Preparation

### 5.3.1. Shell-Produced LNG

#### Upstream Intensity and Local Transport – Shell Produced

As described previously, natural gas production and emissions are obtained for each upstream asset through Shell's reporting channels. The upstream intensities $(CI_{Cu,t}^{up})$, total upstream production $(V_{supply,Cu,t}^{up})$ and production allocated to LNG production $(V_{supply,Cu,t}^{up,LNG})$ by country calculated as part of the upstream allocation exercise (Section 2.2.4) are used as input to the LNG pathway lifecycle analysis.

Volumes are converted into energy content $(E_{supply,Cu,t}^{up}, E_{supply,Cu,t}^{up,LNG})$ using natural gas volume-to-energy conversion factors sourced from the API compendium [5].

#### Upstream Intensity – 3rd Party Gas Production

The upstream emission intensity of 3rd party production $(CI_{Cu,t}^{\overline{up}})$ is calculated separately and used as an input to the calculation. There is no readily available source for the carbon intensity of 3rd party gas production and therefore the same country-average upstream intensity is assumed as that calculated for Shell-produced gas. A standard Shell intensity is used when there are no Shell assets available in a specific country.

#### Pipeline Transportation

The emission intensity of transporting natural gas from upstream assets to LNG facilities via pipeline are calculated using the same approach and factors $(CI_{pipe/d,gas}, GR_{pipe/d,gas})$ used for the pipeline gas pathway (Section 4.3). The distances assumed between upstream assets and liquefaction facilities $(D_{(Au,Al)}^{pipe,LNG})$ are estimated in advance and input into the model.

## Liquefaction

For each LNG producing country ($Al$), the emission intensity associated with the liquefaction process is calculated from emissions ($GHG_{Al,t}^{liq,LNG}$) and LNG production ($E_{Al,t}^{liq,LNG}$) data sourced from Shell reporting channels. The liquefaction intensity ($CI_{Al,t}^{liq,LNG}$) is calculated by

$$CI_{Al,t}^{liq,LNG} = \frac{GHG_{Al,t}^{liq,LNG}}{E_{Al,t}^{liq,LNG}} \quad \text{(Eq. 50)}$$

and input into the lifecycle intensity calculations.

During the liquefaction process, natural gas is assumed to be used as a fuel for operations. Further shrinkage in volume occurs as impurities are removed from the natural gas streams. The reduction factor describing these losses ($GR_{Al,t}^{liq,LNG}$) is taken as an input from Shell data.

In the case of integrated LNG projects, the emissions supplied from Shell reporting channels contain an aggregate of upstream production and liquefaction emissions. They are used with reported production volumes to directly calculate the WtLA intensity.

## LNG Export (Shipping)

The intensity associated with exporting LNG via ships is calculated using a shipping emission factor per unit distance shipped ($CI_{ship/d,LNG}$). The emission factor used takes into account fuel consumption, different engine types (e.g. steam, dual fuel diesel electric, etc) and capacity of Shell vessels, combined with International Maritime Organization’s published emission data for fuel combustion [18]. An estimate of methane slip is included using Shell data.

The shipping distances between exporting liquefaction facilities and importing regasification facilities are estimated using LNG trade volume databases [20]. LNG from a given Shell liquefaction plant ($Al$) can be exported to multiple import locations. The average shipping distance ($D_{Al,t}^{exp,LNG}$) is estimated by weighting the export-import distances for the various export-import pathways by the fraction of total LNG produced and exported to each destination.

LNG consumed as fuel during shipping is estimated using a gas reduction factor ($GR_{ship/d,LNG}$).

## Regasification

During the regasification processes some natural gas may be consumed in the process as fuel. Emissions from regasification facilities are estimated based on publicly available data.

## Distribution via Pipeline

Emissions associated with pipeline distribution from regasification facilities are included in the lifecycle analysis using the same pipeline intensity and reduction factors ($CI_{pipe/d,gas}, GR_{pipe/d,gas}$) as the pipeline gas pathway (Section 4.3). A constant pipeline distance is assumed ($D^{dist,LNG}$).

### 5.3.2. 3rd Party Produced LNG

The lifecycle emission intensity of 3rd party LNG production is assumed to be the same as the global average for Shell-produced LNG.

#### Sales Volumes

Total LNG sales provided from Shell reporting channels are used as an input to the NCI calculations. They are indicative of the quantity of LNG delivered (ex-ship) for regasification. Sales are converted into energy content ($E_{port,t}^{sales,LNG}$) and input into the model calculations.

#### End-Use

As for the pipeline gas pathway, natural gas sold is assumed to be combusted. The same end-use emission intensity ($CI_t^{end\_use,LNG}$) used for the pipeline gas pathway is assumed.

## 5.4. Calculation Overview

### 5.4.1. Shell Produced LNG

#### Upstream Production

For each LNG producing country ($Al$) the LNG production ($E_{Al,t}^{liq,LNG}$) and liquefaction gas reduction factor ($GR_{Al,t}^{liq,LNG}$) are used as inputs to the calculation. The natural gas demand for each country is then calculated from the LNG production by accounting for gas loss during the liquefaction process by

$$E_{demand,Al,t}^{up,LNG} = E_{Al,t}^{liq,LNG} * \left(1 + GR_{Al,t}^{liq,LNG}\right) \quad \text{(Eq. 51).}$$

The total gas demand for LNG production in each country ($Cl$) is

$$E_{demand,Cl,t}^{up,LNG} = \sum_{Al\_in\_Cl} E_{demand,Al,t}^{up,LNG}. \quad \text{(Eq. 52)}$$

The natural gas demand for each LNG producing country is filled, in order of priority, by:

1) natural gas designated ($E_{desig,Al,t}^{up,LNG}$) for liquefaction (if applicable);
2) Shell-produced natural gas allocated to LNG ($E_{supply,Cu,t}^{up,LNG}\big|_{Cu=Cl}$); and,
3) 3rd party produced natural gas ($E_{supply,Cu,t}^{\overline{up},LNG}\big|_{Cu=Cl}$).

The fraction of the demand filled by any designated gas supply is

$$Share_{desig,Al,t}^{up,LNG} = \begin{bmatrix} 1, & if\ E_{desig,Al,t}^{up,LNG} \geq E_{demand,Al,t}^{up,LNG} \\ E_{desig,Al,t}^{up,LNG} / E_{demand,Al,t}^{up,LNG}, & if\ E_{desig,Al,t}^{up,LNG} < E_{demand,Al,t}^{up,LNG} \end{bmatrix}. \quad \text{(Eq. 53)}$$

The share becomes zero for liquefaction projects without designated gas supply.

The ratio of Shell produced feedgas to 3rd party produced feedgas is

$$Share_{supply,Cl,t}^{up,LNG} = \begin{bmatrix} 1, & if\ E_{supply,Cu,t}^{up} \geq E_{demand,Cl,t}^{up} \\ E_{supply,Cu,t}^{up} / E_{demand,Cl,t}^{up} & if\ E_{supply,Cu,t}^{up} < E_{demand,Cl,t}^{up} \end{bmatrix}_{Cu=Cl} \quad \text{(Eq. 54)}$$

where $E^{up}_{supply,Cu,t}$ is the upstream production and $E^{up}_{demand,Cu,t}$ is the in-country demand from all Shell facilities (LNG, GTL, power generation), excluding projects with designated upstream supply. It is assumed that any deficit in Shell-produced natural gas (designated or otherwise) is made up through 3rd party production.

The upstream intensity associated with the varied supply sources for a given country becomes

$$CI^{up,LNG}_{Al,t} = \left(CI^{up,LNG}_{desig,Al,t} * Share^{up,LNG}_{desig,Al,t}\right) + \left(1 - Share^{up,LNG}_{desig,Al,t}\right) * \left[\left(CI^{up,LNG}_{Cu,t} * Share^{up,LNG}_{supply,Cl,t}\right) + \left(CI^{\overline{up},LNG}_{Cu,t} * \{1 - Share^{up,LNG}_{supply,Cl,t}\}\right)\right]. \quad \text{(Eq. 55)}$$

where $CI^{up,LNG}_{desig,Al,t}$ is the upstream intensity of the designated gas, $CI^{up,LNG}_{Cu,t}$ is the country average upstream intensity of Shell-produced gas, and $CI^{\overline{up},LNG}_{Cu,t}$ is the country average upstream intensity of 3rd party produced gas.

## Local Pipeline Transportation

The emission intensity associated with transporting natural gas by pipeline to a liquefaction plant within an LNG producing country ($Al$) is estimated by

$$CI^{pipe,LNG}_{Al} = CI_{pipe/d,gas} * D^{pipe,LNG}_{(Cu,Al)} \quad \text{(Eq. 56)}$$

where $D^{pipe,LNG}_{(Cu,Al)}$ is the country average length of pipeline and $CI_{pipe/d,gas}$ is the pipeline emission factor for transporting natural gas per unit distance.

The fraction of gas consumed during pipeline transport from upstream assets in country ($Cu$) to liquefaction facilities within an LNG producing country ($Al$) is calculated by

$$GR^{pipe,LNG}_{(Cu,Al),t} = GR_{pipe/d,gas} * D^{pipe,LNG}_{(Cu,Al)}. \quad \text{(Eq. 57)}$$

where the pipeline gas reduction factor ($GR_{pipe/d,gas}$).

## Liquefaction

The intensity associated with liquefaction for each LNG producing country ($CI^{liq,LNG}_{Al,t}$) is estimated separately and used as an input to the calculation.

## LNG Export (Shipping)

The emission intensity for LNG shipping is estimated by

$$CI^{exp,LNG}_{Al,t} = CI_{ship/d,LNG} * D^{exp,LNG}_{Al,t} \quad \text{(Eq. 58)}$$

where $D^{exp,LNG}_{Al,t}$ is the average export-import distance and $CI_{ship/d,LNG}$ is the shipping emission factor for shipping LNG per unit distance.

The fraction of LNG consumed during transport, as fuel and methane slip, is calculated by

$$GR^{exp,LNG}_{Al,t} = GR_{ship/d,LNG} * D^{exp,LNG}_{Al,t} \quad \text{(Eq. 59).}$$

where $GR_{ship/d,LNG}$ is an estimated reduction per unit distance travelled.

### Regasification

The intensity associated with regasification ($CI^{regas,LNG}$) and an associated gas reduction factor ($GR^{regas,LNG}$) are used as inputs to the calculation.

### Distribution

The emission intensity for distributing gas from regasification facilities to the point of delivery to customers is calculated by

$$CI^{dist,LNG} = CI_{pipe/d,gas} * D^{dist,LNG} \qquad \text{(Eq. 60)}$$

where $D^{dist,LNG}$ is an estimate of the pipeline length (distance) between regasification facilities and customers.

The fraction of gas consumed during pipeline transport is estimated by

$$GR^{dist,LNG} = GR_{pipe/d,gas} * D^{dist,LNG}. \qquad \text{(Eq. 61).}$$

### WtW per LNG producing country

The WtLA intensity is calculated for each non-integrated liquefaction asset by

$$CI_{Al,t}^{WtLA,LNG} = [CI_{Al,t}^{up,LNG} * (1 + GR_{Al}^{pipe,LNG}) + CI_{Al}^{pipe,LNG}] * (1 + GR_{Al}^{liq,LNG}) + CI_{Al,t}^{liq,LNG} \qquad \text{(Eq. 62)}$$

The WtLA intensity for integrated projects is calculated separately as outlined previously.

The WtT intensity is calculated for each liquefaction asset (including integrated projects) by

$$CI_{Al,t}^{WtT,LNG} = \{[CI_{Al,t}^{WtLA,LNG} * (1 + GR_{Al}^{exp,LNG}) + CI_{Al}^{exp,LNG}] * (1 + GR^{regas,LNG}) + CI^{regas,LNG}\} * (1 + GR^{dist,LNG}) + CI^{dist,LNG} \qquad \text{(Eq. 63)}$$

The WtW intensity is then completed by adding in the intensity of combustion,

$$CI_{Al,t}^{WtW,LNG} = CI_{Al,t}^{WtT,LNG} + CI_{t}^{end\_use,LNG} \qquad \text{(Eq. 64)}$$

The volume of energy delivered to customers from a specific Shell LNG Asset is

$$E_{Al,t}^{end\_use,LNG} = \frac{E_{Al,t}^{liq,LNG}}{(1+GR_{Al}^{exp,LNG})*(1+GR^{regas,LNG})*(1+GR^{dist,LNG})}. \qquad \text{(Eq. 65)}$$

### WtW for all Shell LNG production

The total volume of LNG produced by Shell is

$$E_{t}^{liq,LNG} = \sum_{Al} E_{Al,t}^{liq,LNG}. \qquad \text{(Eq. 66).}$$

The global WtW intensity of LNG produced by Shell and the energy delivered to customers is calculated by

$$CI_{t}^{WtW,LNG} = \frac{\sum_{Al}(CI_{Al,t}^{WtW,LNG} * E_{Al,t}^{end\_use,LNG})}{\sum_{Al} E_{Al,t}^{end\_use,LNG}} \qquad \text{(Eq. 67)}$$

and

$$E_{t}^{end\_use,LNG} = \sum_{Al} E_{Al,t}^{end\_use,LNG}. \qquad \text{(Eq. 68).}$$

### 5.4.2. 3rd party Produced LNG

The volume of 3rd party LNG purchased and subsequently sold by Shell is calculated from total sales. Sales ($E_{port,t}^{sales,LNG}$) are provided in terms of the volume of LNG delivered to regasification facilities. Accordingly, the volume of 3rd party LNG purchased is

$$E_{delivered,t}^{\overline{exp},LNG} = E_{port,t}^{sales,LNG} - E_{t}^{end\_use,LNG} * \left(1 + GR^{regas,LNG}\right) * \left(1 + GR^{dist,LNG}\right). \quad \text{(Eq. 69)}$$

The notation $delivered$ is used to indicate the amount of LNG delivered after export but prior to regasification.

The volume of 3rd party LNG subsequently delivered to customers following regasification and pipeline transport is

$$E_{t}^{\overline{end\_use},LNG} = \frac{E_{delivered,t}^{\overline{exp},LNG}}{\left(1+GR^{regas,LNG}\right)*\left(1+GR^{dist,LNG}\right)} \quad \text{(Eq. 70)}$$

using the same assumptions for regasification and pipeline transmission losses.

The WtT intensity of 3rd party LNG is assumed to be the same as Shell's global WtT.

$$CI_{t}^{\overline{WtW},LNG} = CI_{t}^{WtW,LNG} . \quad \text{(Eq. 71)}$$

### 5.4.3. Shell's Total LNG Portfolio

The volume of energy provided to customers is calculated from LNG sales by

$$E_{port,t}^{end\_use,LNG} = \frac{E_{port,t}^{sales,LNG}}{\left(1+GR^{regas,LNG}\right)*\left(1+GR^{dist,LNG}\right)} \quad \text{(Eq. 72)}$$

accounting for energy lost due to consumption as fuel or fugitive emissions during the regasification and distribution process.

The WtW intensity for all Shell LNG pathways is

$$CI_{port,t}^{WtW,LNG} = \frac{\left(CI_{t}^{\overline{WtW},LNG} * E_{t}^{\overline{end\_use},LNG}\right) + \left(CI_{t}^{WtW,LNG} * E_{t}^{end\_use,LNG}\right)}{E_{port,t}^{end\_user,LNG}}. \quad \text{(Eq. 73)}$$

# 6. Gas-to-Liquids (GTL) Pathway

## 6.1. Lifecycle Pathway

The lifecycle analysis for the Gas-to-Liquids (GTL) pathway (Figure 9) includes the following stages:

1) **production & processing** of natural gas by upstream assets;
2) **transportation** of natural gas via a pipeline to GTL facilities;
3) **processing** of natural gas in GTL facilities;
4) **export** of GTL products by ships;
5) **distribution** of GTL products to customers; and,
6) **consumption** (combustion) of the GTL products

GTL technology, Middle Distillate Synthesis (MDS), converts natural gas to liquid fuels and other products such as lubricant blendstocks. Only the GTL products that are considered energy products (e.g. liquid fuels) are included in Shell's NCI calculation.

The same nomenclature as the oil portfolio is used with the operational portion of the pathway being referred to as the "Well-to-Tank" (WtT) and the lifecycle carbon intensity including end use being referred to as "Well-to-Wheel" (WtW).

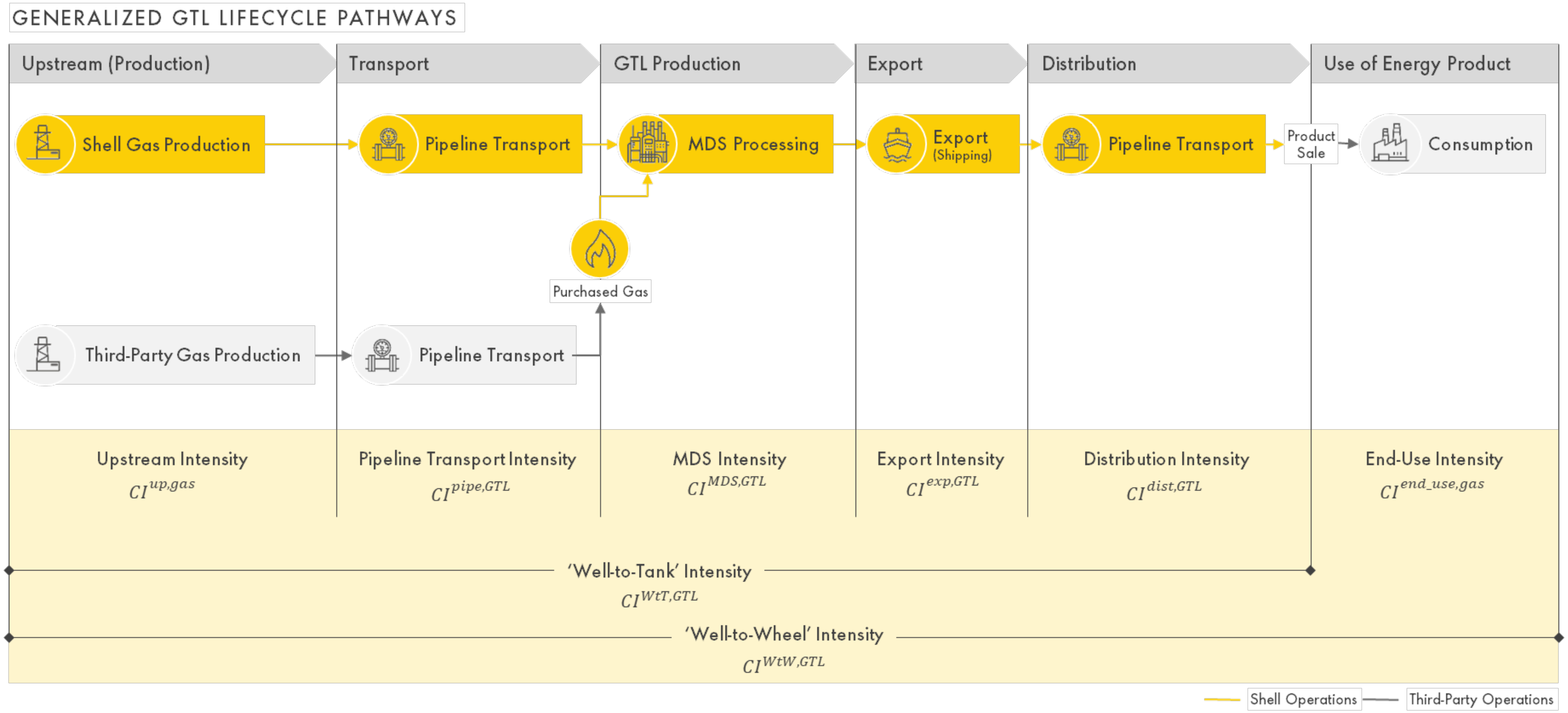


**Figure 9:** Schematic of the pathway for GTL.

## 6.2. Methodology

The general steps used to calculate the WtT intensity of the GTL pathway are as follows.

**Step 1: Calculate the Shell-produced natural gas supply and upstream intensity by country**

- The upstream intensity and volume of Shell-produced natural gas available as feedstock for a given Shell GTL plant is estimated as per the upstream production allocation exercise outlined in Section 2.2.4. The supply and upstream intensity are provided on a country-by-country basis.
- GTL assets with designated natural gas supply are excluded from these calculations.

**Step 2: Calculate the natural gas demand (intake) from Shell GTL assets by country**

- The natural gas demand from Shell GTL assets is calculated per country
- As with LNG, GTL assets may be integrated in which case their gas demand is excluded from the calculation

**Step 3: Balance the natural gas supply and demand from Shell GTL facilities by country**

- The natural gas supply and GTL facility demand is balanced on a country-by-country basis assuming that all allocated Shell-produced gas is used first with any deficits being filled by 3rd party production.
- The fractional split of Shell and 3rd party produced gas is calculated by country and is used later in the analysis to calculate the WtT intensity for each Shell asset.

**Step 4: Calculate the upstream production intensity for each GTL facility with Shell-equity.**

- For each Shell GTL facility, the upstream gas production intensity is calculated using a weighted average of the different gas supplies (e.g. designated, Shell-produced, and 3rd party).

**Step 5: Calculate the pipeline transportation intensity for each GTL facility with Shell-equity.**

- Generalized emission and consumption factors per distance of transport are used to calculate the pipeline transport intensity for the feedgas.

**Step 6: Calculate the production intensity for each GTL asset with Shell-equity.**

- The emission intensity for GTL production is estimated using production volumes and reported emissions.

**Step 7: Estimate the characteristic intensity for export shipping and distribution of GTL products.**

- The emission intensity of exporting and distributing GTL are calculated from emission factors and estimated distances.

**Step 8: Calculate the WtT for each GTL facility with Shell-equity.**

- The WtT intensity is calculated by aggregating the previously calculated weighted average upstream intensity with the characteristic intensities for the pipeline transport, GTL production, export shipping, and distribution stages in the lifecycle pathway.

**Step 9: Calculate the WtW CI for each GTL facility with Shell-equity.**

- The WtW intensity is calculated by adding the end-use consumption intensity to the WtT intensity.

**Step 10: Calculate the average WtW CI for the total Shell-produced GTL supply chain.**

- The portfolio level WtW intensity is calculated by aggregating the WtW intensity for each asset, weighted by the relative fraction of total GTL production.

Integrated GTL projects with designated natural gas feedstocks are handled differently than outlined above. The operational emissions reported for these assets include emissions from upstream production and pipeline transmission, in addition to the GTL production. Accordingly, Steps 1 through 5 are omitted and the reported emission intensity is used directly to calculate the WtT intensity by summing with the intensity of export and distribution.

It is currently assumed that no GTL energy products produced by 3rd parties are sold by Shell and therefore it is not necessary to estimate the intensity of 3rd party GTL production.

## 6.3. Input Data Sources and Preparation

### 6.3.1. Shell Produced GTL

#### Shell Production

Natural gas production and emissions are obtained for each upstream asset through Shell's reporting channels. The upstream intensities $(CI_{Cu,t}^{up})$, total upstream production $(V_{supply,Cu,t}^{up})$ and production allocated to GTL production $(V_{supply,Cu,t}^{up,GTL})$ by county are determined by the upstream allocation exercise (Section 2.2.4). Volumes are converted into energy content $(E_{supply,Cu,t}^{up,GTL})$ using natural gas volume-to-energy conversion factors sourced from the API compendium [6].

#### 3rd Party Production

The upstream emission intensity for 3rd party production is used as an input to the calculation $(CI_{Cu,t}^{\overline{up}})$. The same assumptions and values are used as for the LNG pathway.

#### Local Pipeline Transport

The emission intensity of transporting natural gas from upstream assets to GTL facilities via pipeline are calculated using the same factors $(CI_{pipe/d,gas}, GR_{pipe/d.gas})$ and approach as for the pipeline gas pathway (Section 4.3).

A country average distance of pipeline transport between upstream assets in country $(Cu)$ and a GTL asset $(Ag)$ $(D_{(Cu,Ag)}^{pipe,GTL})$ is estimated and used as input into the calculations.

Pearl GTL is an integrated gas asset; emissions associated with upstream gas production and pipeline transport are included in the emissions reported by the asset. No additional calculation of pipeline transportation emission is therefore required i.e. the notional pipeline length is assumed to be 0km.

### GTL production

The emission intensity for GTL production ($CI_{Ag,t}^{MDS,GTL}$) is calculated from the reported emissions and production from the asset. For integrated assets it is not possible to isolate the GTL production intensity as the asset emission include the upstream gas production and transport.

The fraction of gas lost due to consumption during GTL production ($MJ_{NG}/MJ_{GTL}$; $GR_{Ag,t}^{MDS,GTL}$) is taken as an input for non-integrated assets.

### Export

The intensity associated with exporting GTL via ships is calculated using a shipping emission factor per unit distance shipped. The shipping distance from the Pearl facility is set as a constant representing that from Qatar to Rotterdam, The Netherlands. For the Shell MDS facility in Bintulu, the reference distance used is from Bintulu, Sarawak to Osaka, Japan.

### Distribution

The emission intensity of distributing GTL products from import terminals to point of sale ($CI^{dist,GTL}$) is used as an input to the calculations. The same intensity is assumed as that used for the oil pathway [10].

### End-use

The end-use of GTL is assumed to be combustion.

## 6.4. Calculation Overview

### 6.4.1. Shell Produced GTL

Integrated and non-integrated GTL assets are handled differently for the first stages of the lifecycle analysis (upstream through GTL production). Integrated assets are treated as described in Section 6.2. In the case of non-integrated GTL projects, the upstream intensity and local pipeline transport needs to be calculated and combined with the intensity of processing natural gas into GTL products.

Both integrated and non-integrated GTL projects follow the same approach to accounting for the export, distribution, and end-use stages in the lifecycle analysis.

### Upstream Production

For each non-integrated GTL asset with Shell-equity ($Ag$), the GTL production volume ($E_{Ag,t}^{MDS,GTL}$), and the gas reduction factor for the GTL production ($GR_{Ag,t}^{MDS,GTL}$) are used as input to the calculation. The natural gas demand for each GTL asset is calculated by accounting for gas loss during pipeline transport and GTL production, by

$$E_{demand,Ag,t}^{up,GTL} = E_{Ag,t}^{MDS,GTL} * \left(1 + GR_{Ag,t}^{MDS,GTL}\right) \quad \text{(Eq. 74).}$$

The total natural gas demand for GTL production in each country ($Cg$) is

$$E^{up,GTL}_{demand,Cg,t} = \sum_{Ag\_in\_Cg} E^{up,GTL}_{demand,Ag,t}. \quad \text{(Eq. 75)}$$

The natural gas demand for non-integrated GTL in each country is filled, in order of priority, by:

1) Shell-produced natural gas allocated to GTL ($E^{up,GTL}_{supply,Cu,t}\big|_{Cu=Cg}$); and;
2) 3rd party produced natural gas ($E^{\overline{up},GTL}_{supply,Cu,t}\big|_{Cu=Cg}$).

The ratio of Shell produced supply to 3rd party produced supply is

$$Share^{up,GTL}_{supply,Cg,t} = \begin{bmatrix} 1, & if\ E^{up}_{supply,Cu,t} \geq E^{up}_{demand,Cg,t} \\ E^{up}_{supply,Cu,t}/E^{up}_{demand,Cg,t} & if\ E^{up}_{supply,Cu,t} < E^{up}_{demand,Cg,t} \end{bmatrix}_{Cu=Cg} \quad \text{(Eq. 76)}$$

where $E^{up,GTL}_{supply,Cu,t}$ is the upstream production allocated to GTL production and $E^{up}_{demand,Cu,t}$ is the in-country demand from all Shell facilities (LNG, GTL, power generation), excluding gas supply designated to a specific asset. It is assumed that any deficit in Shell-produced natural gas (designated or otherwise) is made up through 3rd party gas supply.

The upstream intensity associated with the varied supply sources becomes

$$CI^{up,GTL}_{Ag,t} = \left[\left(CI^{up,GTL}_{Cu,t} * Share^{up,GTL}_{supply,Cg,t}\right) + \left(CI^{\overline{up},GTL}_{Cu,t} * \{1 - Share^{up,GTL}_{supply,Cg,t}\}\right)\right]_{Cu=Cg} \quad \text{(Eq. 77)}$$

where $CI^{up,GTL}_{Cu,t}$ is the country average upstream intensity of Shell-produced gas, and $CI^{\overline{up},GTL}_{Cu,t}$ is the country average upstream intensity of 3rd party produced gas.

## Local Pipeline Transportation

For non-integrated GTL assets, the emission intensity associated with transporting natural gas by pipeline to a GTL production asset ($Ag$) is estimated by

$$CI^{pipe,\mathrm{GTL}}_{Ag} = CI_{pipe/d,gas} * D^{pipe,GTL}_{(Cu,Ag)} \quad \text{(Eq. 78)}$$

where $D^{pipe,GTL}_{(Cu,Ag)}$ is the country average length of pipeline to the asset and $CI_{pipe/d,gas}$is the pipeline emission factor used as an input to the calculation.

The fraction of gas consumed during transport is estimated by

$$GR^{pipe,GTL}_{Ag} = GR_{pipe/d,gas} * D^{pipe,GTL}_{(Cu,Ag)} \quad \text{(Eq. 79).}$$

where $GR_{pipe/d,gas}$ is an estimate of the gas loss per unit distance travelled.

## GTL Production

The intensity associated with GTL production is calculated separately for each GTL facility with Shell-equity ($CI^{MDS,GTL}_{Ag,t}$) from reported emission and production data and used as an input to the calculation. The proportion of the outturn of the GTL asset which is considered to be energy products ($E^{end\_use,GTL}_{Ag,t}$) is calculated from total asset production volume ($E^{MDS,GTL}_{Ag,t}$) and the GTL product split ($W_{Prod,Ag,t}$).

## Export Shipping

The emission intensity associated with GTL shipping is estimated by

$$CI^{exp,GTL}_{Ag} = CI_{ship/d,GTL} * D^{exp,GTL}_{Ag} \quad \text{(Eq. 80)}$$

where $D_{Ag}^{exp,GTL}$ is average export-import distance and $CI_{ship/d,GTL}$ is the shipping emission factor for shipping GTL per unit distance.

### Distribution

The distribution emission intensity ($CI^{dist,GTL}$) is sourced from publicly available data and used as an input into the calculation.

## 6.4.2. WtW intensity per GTL Asset

The WtT intensity is calculated for each non-integrated GTL assets by

$$CI_{Ag,t}^{WtT,GTL} = [CI_{Ag,t}^{up,GTL} * (1 + GR_{Ag}^{pipe,GTL}) + CI_{Ag}^{pipe,GTL}] * (1 + GR_{Ag}^{MDS,GTL}) + CI_{Ag,t}^{MDS,GTL} + CI^{exp,GTL} + CI^{dist,GTL}.$$

(Eq. 81)

The upstream, pipeline transport, and MDS intensity is combined for the integrated GTL assets.

The WtW intensity is then completed by adding in the intensity of combustion,

$$CI_{Ag,t}^{WtW,GTL} = CI_{Ag,t}^{WtT,GTL} + CI_{t}^{end\_use,GTL} \quad \text{(Eq. 82)}$$

## 6.4.3. WtW for Total Shell GTL Production

The total volume of GTL produced by Shell assets is

$$E_{t}^{end\_use,GTL} = \sum_{Ag}(E_{Ag,t}^{MDS,GTL} * W_{Prod,Ag,t}) \quad \text{(Eq. 83).}$$

The global WtW intensity is calculated by

$$CI_{t}^{WtW,GTL} = \frac{\sum_{Ag}\left(CI_{Ag,t}^{WtW,GTL} * E_{Ag,t}^{end\_use,GTL}\right)}{\sum_{Ag} E_{Ag,t}^{end\_use,GTL}} \quad \text{(Eq. 84)}$$

## 6.4.4. Shell's Total GTL Portfolio

Since Shell currently sells no GTL energy products produced by 3rd parties, Shell's sales ($E_{t}^{sales,GTL}$) of GTL energy products are equivalent to Shell's GTL production

$$E_{t}^{sales,GTL} = E_{t}^{end\_use,GTL} \quad \text{(Eq. 85)}$$

The associated portfolio level WtW intensity is equivalent to the global WtW intensity of Shell GTL production

$$CI_{port,t}^{WtW,GTL} = CI_{t}^{WtW,GTL}. \quad \text{(Eq. 86)}$$

# 7. Biofuels Pathway

## 7.1. Lifecycle Pathway

The lifecycle analysis for the biofuel pathway (Figure 10) includes the following stages:

1) **production** of biofuel products;
2) **local transportation** of biofuel products;
3) **export transportation** of biofuel products via shipping;
4) **distribution** of biofuel products to customers; and,
5) **consumption** (combustion) of the biofuel energy products.

Liquid biofuels, like Fatty Acid Methyl Esters (FAME, biodiesel), bioethanol, and Hydroprocessed Esters and Fatty Acids (HEFA, also known as sustainable aviation fuel, SAF) are produced from a variety of organic feedstocks ranging from waste streams (e.g. used vegetable oils, animal fats, and wood by-products) to crop oils and sugar cane.

The ‘production’ stage of the lifecycle analysis captures the emissions for feedstock production and transportation to processing facilities (where applicable), and the biofuel conversion process. Associated emission intensities are also known as “Well-to-Gate” (WtG) intensities.

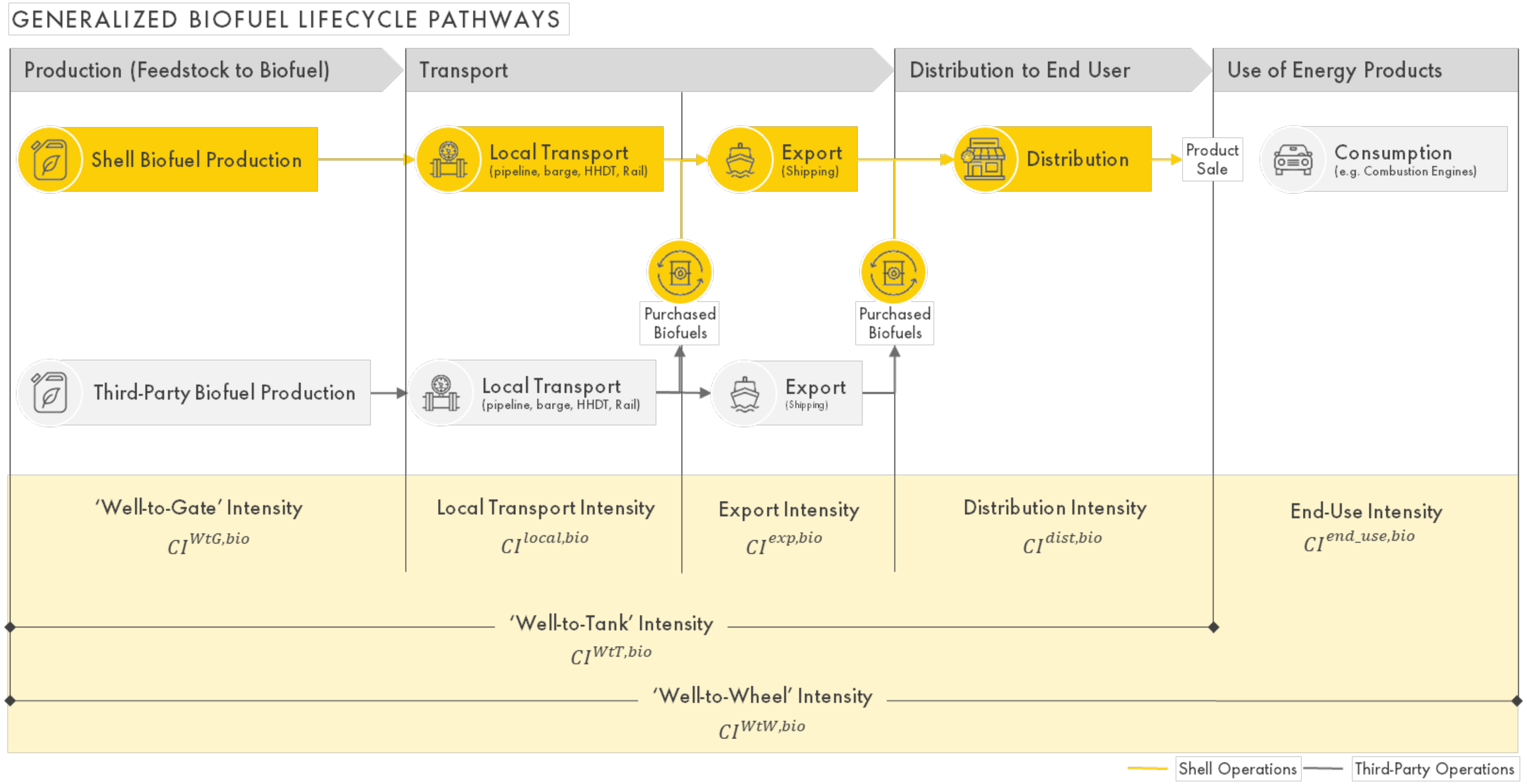


**Figure 10:** Schematic of the pathway for biofuels.

## 7.2. Methodology

The lifecycle emission intensity for biofuels produced at Shell or 3rd party facilities is estimated using the same calculation steps.

**Step 1: Obtain the production intensity for each biofuel production method.**

- The emission intensity of biofuel production varies by feedstock being converted and technology used. The WtG intensity for each feedstock-product pair by region are sourced from publicly available data.

**Step 2: Calculate the intensity of local transportation using constant emission factors and estimated transport distances**

- A global assumption is made for the local transportation distance in the absence of country- or region-specific data.

**Step 3: Calculate the intensity of export transportation using emission factors and estimated transport distances**

- Biofuels produced by a Shell asset may be consumed domestically or exported. In the case of export, shipping emissions are estimated using emission factors and the shipping export and import destinations.

**Step 4: Obtain the intensity of additional distribution to customers and end-use intensity**

- The same distribution intensity used for oil products is assumed for biofuels
- The end use intensity assumes zero $CO_2$ emissions but accounts for $CH_4$ and $N_20$ emissions during combustion.

**Step 5: Calculate the WtW intensity for each asset and type of biofuel (feedstock-product pair by region)**

- WtW intensity is calculated using the intensities assumed for production (WtG), export, distribution and end-use.

**Step 6: Calculate the WtW intensity for Shell's biofuel portfolio using sales data**

- The overall WtW intensity of all biofuels sold by Shell is calculated on a weighted average basis using the individual WtW intensities.
- The total biofuel sales volume is used as an input to the calculation. The amount of biofuels is deducted from the total oil product sales volume to prevent double counting.

Biofuel sales are aggregated using the following regions: 1) Africa, 2) Asia Pacific, 3) Europe, 4) Latin America, 5) Middle East, 6) North America, Russia (CIS), and 7) The Caribbean.

## 7.3. Input Data Sources and Preparation

### 7.3.1. Biofuel Production

#### Shell Produced

Shell biofuel production is primarily from Raizen (a Shell-Cosan joint venture). The WtG intensity ($CI^{WtG,bio}_{(feed,prod),Rb,t}$) is derived from publicly available data [22].

Shell biofuel production volumes by feedstock input and product type are sourced from Shell's reporting channels.

#### 3rd party Produced Biofuels

The characteristic WtG intensities ($CI^{\overline{WtG}}_{(feed,prod),Rb,t}$) for each feedstock-product pair and region of production ($Rb$) are sourced from publicly available data. The emission intensities for U.S. biofuel production pathways are taken from EPA RFS2 [22] and the emission intensity of European production pathways are taken from the Renewable Energy Directive [23] and the BioGrace model [24]. The emission intensity for production pathways in the Asia-Pacific are from various publications (cassava ethanol [25], molasses ethanol [26], coconut biodiesel [27] and palm oil biodiesel [28]).

3rd party biofuel purchases by feedstock type, feedstock origin, and biofuel product type are sourced from Shell reporting channels. The data is used to:

- determine the feedstock-product type pair for mapping the appropriate WtG emission intensities;
- determine the fractional contribution of the specific feedstock-product volume to total biofuel sales;
- estimate import-export distances for biofuels.

### 7.3.2. Biofuel Transportation

Biofuels produced by a single asset are either consumed domestically and/or exported. Biofuels are collected from production facilities and transported directly to customers or to bulk terminals by various methods (e.g. truck, rail, barge and pipeline) where they are then exported via ocean tankers. For domestic consumption, only local transportation emissions are considered. Both local and shipping emissions are considered for exported biofuels.

#### Local Transportation

A constant local transport emissions factor per unit distance ($CI_{local/d,bio}$) is used which accounts for various modes of transportation. A single global assumption is used for the local transportation distance in the absence of better information.

### Export Transportation

A constant shipping emission factor per distance of transport $(CI_{ship/d,bio})$ is used in the NCI calculation. Export (shipping) distances $\left(D^{exp,bio}_{(Rb,Rd)}\right)$ vary by production $(Rb)$ and destination $(Rd)$ region such that:

$$D^{exp,bio}_{(Rb,Rd)} = \begin{bmatrix} 0\text{km}, & if \text{ Rb} = \text{ Rd} \\ variable, & if \text{ Rb} <> \text{ Rd} \end{bmatrix} . \quad \text{(Eq. 87)}$$

Shipping distances distance between each export location (region of biofuel production, $Rb$) and destination location $(Rd)$ $(D^{exp,bio}_{(Rb,Rd)})$ are estimated using an online seaport calculation tool [29].

Shell Produced

The destination location for Shell-produced (i.e. Raizen) biofuel products is sourced from the Brazil National Agency for Petroleum, Natural Gas and Biofuels [30].

3rd Party Produced

3rd party produced biofuels purchased by Shell are assumed to have been exported from the region of feedstock production to the region of sale.

## 7.3.3. Distribution

The same distribution intensity $(CI^{dist,bio})$ is used for biofuels as is used for the oil and GTL pathways.

## 7.3.4. End-Use

By convention the $CO_2$ emissions from the combustion of biofuels are assumed to be zero but $CH_4$ and $N_20$ emissions during combustion are accounted for in the combustion emissions factor.

## 7.3.5. Sales

### Shell Produced

Production volumes from Shell biofuel assets are assumed to represent the final volume of Shell-produced biofuels products delivered to customers.

### 3rd party Produced

The total volume of biofuels purchased from 3rd party suppliers and used in Shell's gasoline and diesel blends worldwide is taken from the Shell Sustainability Report. These volumes represent the volume of biofuel product delivered to customers.

## 7.4. Calculation Overview

### 7.4.1. Shell-Produced Biofuels

#### Production

For each biofuel production asset with Shell-equity ($Ab$), the emission intensity of production ($CI^{WtG,bio}_{(feed,prod),Ab,t}$) is sourced from publicly available data and used as an input into the calculation. The intensities vary by feedstock ($feed$) and product produced ($prod$).

The production volume ($E^{prd,bio}_{(feed,prod),Ab,Rd,t}$) exported to each to region ($Rd$) is sourced from publicly available data and used an input to the calculation. It is assumed that no biofuel is consumed as fuel or lost during transportation (local or export), and therefore the production volume is equivalent to the final volume delivered to customers,

$$E^{end\_use,bio}_{(feed,prod),Ab,Rd,t}. = E^{prd,bio}_{(feed,prod),Ab,Rd,t}. \quad \text{(Eq. 88)}$$

#### Local Transportation

The emission intensity associated with transporting biofuels by pipeline, or other means, to local processing or export facilities is estimated by region of production ($Rb$) by

$$CI^{local,\mathrm{bio}}_{Rb} = CI_{local/d,bio} * D^{local,\mathrm{bio}}_{\mathrm{Rb}} \quad \text{(Eq. 89)}$$

where $D^{local,bio}_{Rb}$ is the estimated transport distance and $CI_{local/d,bio}$is the transportation intensity.

<u>Export</u>

The emission intensity for exporting biofuels via ships is estimated by

$$CI^{exp,\mathrm{bio}}_{Ab} = CI_{ship/d,bio} * D^{ship,bio}_{(Rb,Rd)} \quad \text{(Eq. 90)}$$

where $D^{ship,bio}_{(Rb,Rd)}$ is estimated distance between each region of production ($Rb$) and destination location ($Rd$) and $CI_{ship/d,bio}$ is the shipping emission factor for shipping biofuels per unit distance.

#### Distribution

The same constant distribution intensity ($CI^{dist,\mathrm{bio}}$) used for oil products is also used for biofuel products.

#### WtW per Biofuel Asset per Import Region

For Shell-produced biofuels, the full life cycle intensity is calculated for each producing asset ($Ab$), by feedstock source ($feed$), product produced ($prod$), and destination region of product (imported to) ($Rd$).

The WtT intensity is

$$CI^{WtT,bio}_{(feed,prod),(Ab,\mathrm{Rd}),t} = CI^{WtG,bio}_{(feed,prod),Ab,t} + CI^{local,bio}_{Rb,t} + CI^{exp,bio}_{(Rb,Rd),t} + CI^{dist,bio} \quad \text{(Eq. 91)}$$

The WtW intensity is completed by adding in the intensity of combustion such that

$$CI^{WtW,bio}_{(feed,prod),(Ab,Rd),t} = CI^{WtT,bio}_{(feed,prod),(Ab,Rd),t} + CI^{end\_use,bio}_{prod} \quad \text{(Eq. 92)}$$

### WtW for all Shell Biofuel Production

The WtW intensity and energy delivered to customers from all Shell biofuel production is calculated by

$$CI^{WtW,bio}_{t} = \frac{\sum_{Ab}\left(CI^{WtW,bio}_{(feed,prod),(Ab,Rd),t} * E^{end\_use,bio}_{(feed,prod),(Ab,Rd),t}\right)}{\sum_{(Ab,Rd)}\sum_{(feed,prod)} E^{end\_use,bio}_{(feed,prod),(Ab,Rd),t}}. \quad \text{(Eq. 93)}$$

and

$$E^{end\_use,bio}_{t} = \sum_{Ab}\sum_{(feed,prod)} E^{end\_use,bio}_{(feed,prod),Ab,t}. \quad \text{(Eq. 94).}$$

where all biofuel products produced at all facilities are aggregated.

## 7.4.2. 3rd Party Produced Biofuels

The calculation of the full life cycle intensity of biofuels produced by 3rd parties is driven by the sales volumes. Shell biofuel sales obtained from reporting channels are prepared (e.g. converted to energy) for input into the NCF calculation with indicators for feedstock source ($feed$), product type produced ($prod$), feedstock production region ($Rb$), and sales region ($Rd$).

These sales ($E^{sales,bio}_{(feed,prod),(Rb,Rd),t}$) equate to the volume of 3rd party produced biofuels purchased and subsequently resold by Shell,

$$E^{\overline{end\_use},bio}_{(feed,prod),(Rb,Rd),t} = E^{sales,bio}_{(feed,prod),(Rb,Rd),t}. \quad \text{(Eq. 95)}$$

The lifecycle analysis follows the same approach used for Shell produced biofuels with the WtG intensities being sourced from publicly available data.

The WtT intensity is calculated by

$$CI^{\overline{WtT},bio}_{(feed,prod),(Rb,R\_imp),t} = CI^{\overline{WtG},bio}_{(feed,prod),Ab,t} + CI^{local,bio}_{Rb,t} + CI^{exp,bio}_{(Rb,Rd),t} + CI^{dist,bio}. \quad \text{(Eq. 96)}$$

The WtW intensity is completed by adding the intensity of combustion such that

$$CI^{\overline{WtW},bio}_{(feed,prod),(Ab,R\_imp),t} = CI^{\overline{WtT},bio}_{(feed,prod),(Ab,Rd),t} + CI^{end\_use,bio}_{prod}. \quad \text{(Eq. 97)}$$

### WtW for all 3rd party Biofuel Production

The WtW intensity and energy delivered to customers from all 3rd party biofuel production is calculated by

$$CI^{\overline{WtW},bio}_{t} = \frac{\sum_{Ab}\left(CI^{\overline{WtW},bio}_{(feed,prod),(Ab,Rd),t} * E^{\overline{end\_use},bio}_{(feed,prod),(Ab,Rd),t}\right)}{\sum_{(Ab,Rd)}\sum_{(feed,prod)} E^{\overline{end\_use},bio}_{(feed,prod),(Ab,Rd),t}}. \quad \text{(Eq. 98)}$$

and

$$E^{\overline{end\_use},bio}_{t} = \sum_{Ab}\sum_{(feed,prod)} E^{\overline{end\_use},bio}_{(feed,prod),Ab,t}. \quad \text{(Eq. 99).}$$

where all 3rd party produced biofuel products are aggregated.

### 7.4.3. Shell's Total Biofuels Portfolio

The associated portfolio level WtW intensity is

$$CI_{port,t}^{WtW,\text{bio}} = \frac{\left(CI_t^{\overline{WtW},bio} * E_t^{\overline{end\_use},bio}\right) + \left(CI_t^{WtW,bio} * E_t^{end\_use,bio}\right)}{E_t^{\overline{end\_use},\text{bio}} + E_t^{end\_use,\text{bio}}} \quad \text{(Eq. 100)}$$

and the total volume of biofuel energy products delivered to customers ($E_{port,t}^{end\_use,\text{bio}}$) is

$$E_{port,t}^{end\_use,\text{bio}} = E_t^{\overline{end\_use},bio} + E_t^{end\_use,bio}. \quad \text{(Eq. 101)}$$

# 8. Electricity Pathway

## 8.1. Lifecycle Pathway

The lifecycle analysis for the electricity pathway (Figure 11) includes the following stages:

1) **production** of fuel (if applicable);
2) **local transportation of** fuel (if applicable);
3) **power generation;**
4) **distribution** of electricity to customers; and,
5) notional **consumption** of the electricity.

Renewable electrical energy pathways (e.g. solar or wind) only need to account for the operational emissions of wind or solar assets, whilst the fossil-fuel power generation pathway must also include the upstream emissions associated with fuel production and transportation. In line with other pathways, the emissions associated with construction and decommissioning of assets are not within the scope of the NCI calculation.

Shell's generation portfolio consists of gas-fired power generation and renewable power generation assets; in addition, Shell purchases power generated by 3rd parties for resale.

## 8.2. Methodology

Total electricity sales along with Shell-generated electricity production data drives the lifecycle emission analysis of Shell's electricity portfolio. Electricity sold by Shell is categorized as:

1) Shell generated: Electricity generated by assets with Shell Equity including electricity from thermal and renewable assets (e.g. gas fired power plants, wind, and solar).;
2) Power generated by 3rd parties:
    a. Certified renewable power: Electricity sold with Renewable Energy Certificates (RECs) retired by Shell or transferred to the customer;
    b. Power Purchase Agreements (PPAs): Electricity sourced via a PPA and sold by Shell;
    c. Residual grid: Electricity purchased from the grid for resale by Shell.

The lifecycle emission analysis approach varies between each of these categories and is completed separately and then aggregated to estimate the overall emission intensity of Shell's electricity sales.

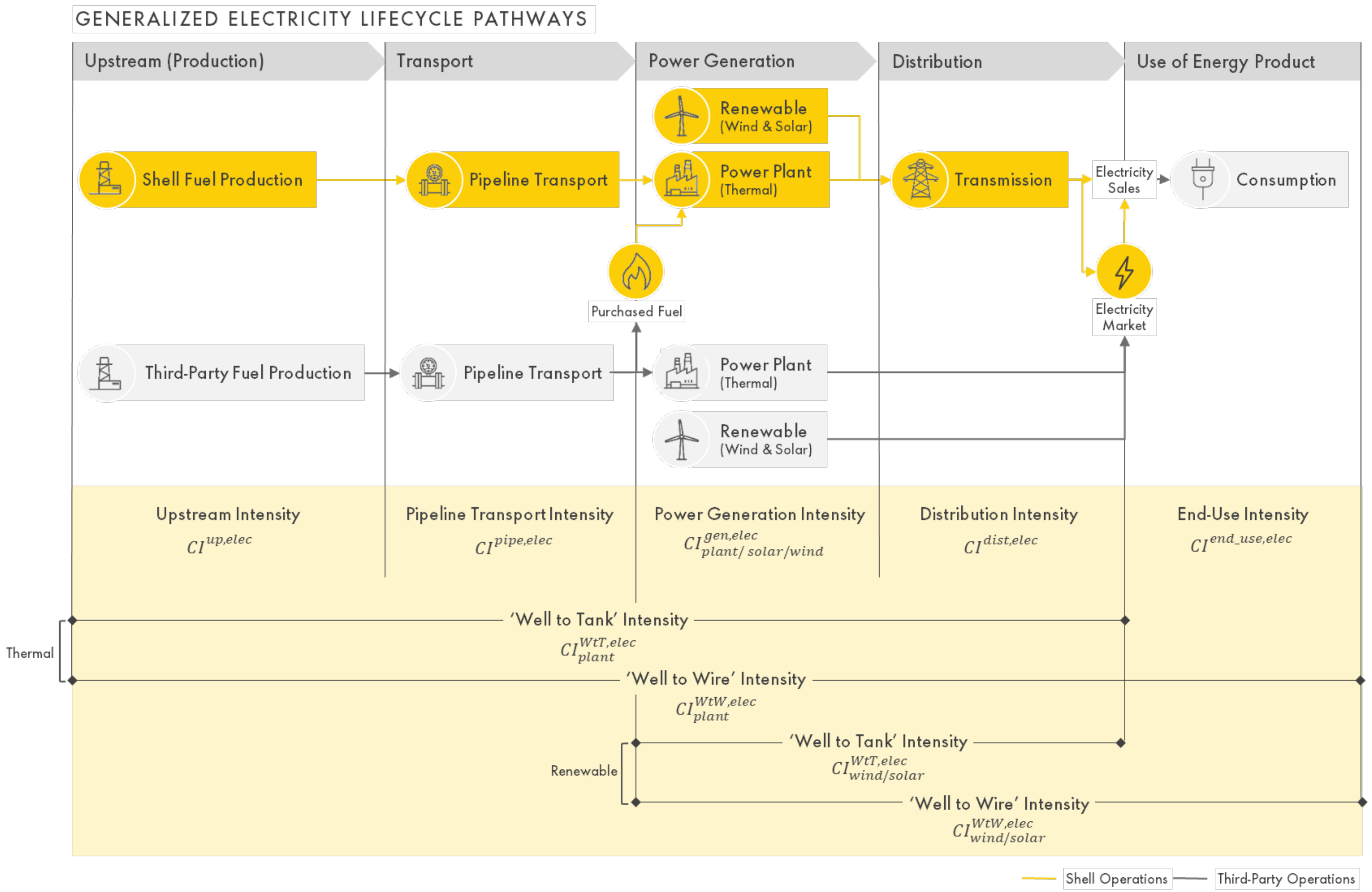


**Figure 11:** Schematic of the pathway for electricity.

The emission intensity for power generation varies significantly depending on the electricity generation technologies used. The NCI calculation aims to capture this variation by using appropriate emission intensities for different technologies. For Shell-generated electricity, emission intensities are estimated using reported emission data whenever possible, and publicly available emissions factors when Shell data is not available. For 3rd party generated electricity (RECs and PPAs), publicly available emissions factors are used for each generation technology. Residual grid emission intensities are estimated using publicly or commercially available data that also recognises the varied generation technology mixes present in different markets.

### 8.2.1. Shell Generated Electricity

Electricity produced by assets with Shell equity includes:

1) fossil fuel power generation (gas-fired power plant); and,
2) renewable power generation.

The lifecycle emission intensity for Shell-produced electricity is estimated separately for each of these categories, and for each type of renewable electricity generation asset (i.e. wind and solar). Certain Shell assets are not modelled individually, instead the power generated by these assets is included in country level sales totals and is accounted for at a residual grid intensity.

For those Shell assets which are modelled individually, the steps taken in the lifecycle intensity analysis are summarized as:

**Step 1: Estimate the emission intensity associated with producing and transporting fuel used for power generation**

- The emission intensity associated with the production and transportation of fuel is calculated using the country-average intensity of Shell-produced and 3rd party produced fuel.

**Step 2: Estimate the power generation intensity and volume of electricity generated by each asset**

- The emission intensity and volume generated for Shell power generation operations is determined from the operational emissions and electricity generation data.

**Step 3: Use the intensities from the preceding stages to estimate the lifecycle emission intensity for power generated by each power generation asset with Shell-equity.**

- The lifecycle intensity is determined by aggregating the characteristic intensities from fuel production through distribution.

**Step 4: Determine total electricity delivered to customers by asset**

- If possible transmission losses are estimated and used along with the power generation data to calculate the electrical energy delivered to customers.
- Otherwise, the volume of power generated is assumed to be equivalent to the volume of power delivered to customers.

The lifecycle intensity analysis steps for Shell renewable electricity generation follow the same general approach outlined above except that Step 1 is redundant. Additionally, the lifecycle intensities for Shell solar and wind generation are based on publicly available emissions factors [31] rather than operational emissions data.

### 8.2.2. Power Purchase Agreements

Shell may enter a PPA to purchase power for resale. In this case emission intensities are either based on a specific intensity associated with the PPA or are estimated using publicly available emissions factors for the appropriate power generation technology. The general steps taken to calculate the emission intensity of power sourced through PPAs are summarized as:

- PPA contracts are used to determine either the specific power generation intensity or the generation technology, along with the total volume of power supplied.
- If required, the appropriate technology-specific emissions factor is sourced from publicly available data.
- If required, transmissions losses may be separately estimated and used as inputs to calculate the overall lifecycle emission intensity of power sourced via the PPA.

### 8.2.3. Certified renewable Power

The emission intensity of certified renewable power sold by Shell is estimated as follows:

**Step 1: Establish the volume of electricity sold by generation technology in each market**

- Renewable energy certificates (REC) retired or transferred by Shell are used to determine the volume and generation technology for renewable power sold by Shell.

**Step 2: Establish the lifecycle emission intensity associated with different renewable power generation technologies**

- Emissions intensities for the various renewable power generation technologies are sourced from publicly available data.
- Where possible market specific emissions factors are used, otherwise global factors may be applied.
- If required, transmissions losses may be separately estimated and used as inputs to calculate the overall lifecycle emission intensity of renewable power.

### 8.2.4. Grid Electricity

Electricity sales not accounted for in the first three categories are assumed to be purchased from the grid for resale by Shell. The emission intensity for these sales is assumed to be that of the residual grid in each market. The residual grid intensity is the average intensity of all non-renewable[5] power generation within a market. Accounting for sales of grid power using the residual grid intensity, rather than an overall market average including renewables, ensures that there is no double counting between sales of certified renewable power and sales of grid power. The generalized approach to estimating the intensity of grid power sales is:

**Step 1: Establish the volume of electricity sold**

[5] Non-renewable is defined as oil-, coal, or gas-fired power generation and nuclear generation.

- Total electricity sales are used to estimate the volume of electricity purchased from the grid for resale on a market-by-market basis. Grid electricity sales are defined as the portion remaining after removing any renewable electricity or electricity sourced from PPAs.

**Step 2: Establish the residual emission intensity on a market-by-market basis**

- Emission intensity and/or electricity grid emission and generation data from publicly or commercially available sources are used to calculate the residual grid intensity. Emissions from upstream fuel production and transmission losses are calculated separately in cases where they are not included in the national/regional grid factors.

### 8.2.5. Shell's Total Electricity Portfolio

Finally, the individual emissions intensities for all categories of power sales are aggregated to give an overall emission intensity for the electricity pathway. The individual intensities for each category are weighted by their fractional portion of sales. Total electricity sales are also calculated.

The total electricity portfolio CI and sales are represented on a fossil fuel equivalent basis in the NCI calculation. Electrical energy is converted to a fossil-fuel equivalent measure of energy to account for the difference in the utility of electrical energy compared to the hydrocarbon-based energy product pathways that currently make up the majority of Shell's energy product sales. For consistency the lifecycle intensities for power generation are also converted to a fossil-equivalent basis.

## 8.3. Input Data Sources and Preparation

### 8.3.1. Shell Generated

#### Upstream Production

Shell Produced

Natural gas production and emissions are obtained for each upstream asset through Shell's reporting channels. The upstream intensities $(CI_{Cu,t}^{up})$, total upstream production $(V_{supply,Cu,t}^{up})$ and production allocated to electricity generation $(V_{supply,Cu,t}^{up,elec})$ by county are determined by the upstream allocation exercise (Section 2.2.4 and Appendix 2).

3rd party Produced

The same 3rd party upstream intensities $(CI_{Cu,t}^{up})$ are used as for other pathways. The volume of 3rd party natural gas production is determined as per the upstream allocation exercise.

Local Transport

The local transport of fuel via pipeline to power generation facilities can be accounted for within the NCI calculation. Pipeline emission intensity and fuel reduction are calculated using the same approach as for other pathways. However due to data limitations the distance ($D^{pipe,elec}_{(Au,Ae)}$) between upstream assets ($Au$) and power generation assets ($Ae$) is currently set to zero.

### Electricity Generation

For each Shell thermal power generation asset ($Ae$), power generation capacity, fuel intake requirements, percentage of total fuel intake that is natural gas (gas fuel-fraction; $GF^{elec}_{Ae,t}$), and emission data ($GHG^{elec}_{plant,Ae,t}$) are used as input to the NCI calculation. These metrics are sourced from Shell reporting channels. The gas-fuel fraction is assumed to be 100% for gas-fired facilities, <100% for co-firing facilities, and 0 for non-gas plants.

The amount of power generated by a plant ($E^{gen,\text{elec}}_{plant,elec,Ae,t}$) is provided in terms of electrical energy, which is denoted by the $elec$ subscript.

Power generation efficiency ($Eff_{Ae,t}$) factors are calculated for each asset using power generation capacity and fuel requirement data. This ratio of fuel intake to the volume of electricity generated ($E_{elec}/E_{fuel}$) is used to calculate the fuel demand from a given power generation asset.

Shell renewable power generation volumes by technology type are sourced from Shell reporting channels. The operational emission intensity for wind and solar power generation is assumed to be constant over time and by location. The emissions factors are sourced from publicly available data [31].

### Distribution

Due to data limitations, the fraction of the total generated power lost during transmission ($TR^{dist,elec}$) between the asset and the point of delivery to a customer is assumed to be zero for Shell generation assets.

## 8.3.2. 3rd Party Generation

### PPA, REC, and Grid

Sales of electricity generated by 3rd parties are categorized as power purchase agreements ($PPA$, ($E^{\overline{sales},elec}_{PPA,elec,Bs,Re,t}$), certified renewable electricity ($REC$, $E^{\overline{sales},elec}_{REC,elec,Bs,Re,t}$), and power purchased from the regional electrical grid ($grid$, $E^{\overline{sales},elec}_{grid,elec,Bs,Re,t}$). Accents on the $sales$ superscript denote electricity generated by 3rd parties. $Re$ denotes region / market, which can vary in spatial extent pending the nature of the grid and PPAs, as well as the regional breakdown of sales data available.

The amount of 3rd party produced electricity purchased and subsequently re-sold is determined from sales data provided from Shell reporting channels. Renewable energy certificates are used to determine the volume and technology type of renewable power. Similarly, volumes and generation technology are taken from PPA contracts.

The lifecycle emission intensities for various power generation technologies ($CI_{tech,elec,Re,t}$) and/or grid intensity data are prepared and used as an input to the NCI calculation. Intensities are directly sourced or calculated using publicly or commercially available data.

Technology specific and residual grid intensities are adjusted, if required, to account for emissions associated with feedstock production and transport, and transmission losses.

## 8.4. Calculation Overview

### 8.4.1. Shell Generated Electricity

#### Shell Fossil-Fuel Power Generation

Fuel Production

Natural gas is used as a fuel source for power generation. The power generated ($E^{gen,\text{elec}}_{elec,Ae,t}$) is used to calculate the volume of fuel demanded by each asset by

$$E^{up,elec}_{demand,Ae,Ce,t} = \frac{E^{gen,elec}_{elec,Ce,t} * GF^{elec}_{Ae,t}}{Eff_{Ae,t}} \quad \text{(Eq. 102)}$$

where $GF^{elec}_{Ae,t}$ is the percentage of total fuel intake that is natural gas and $Eff_{Ae,t}$is the power plant efficiency factor describing the volume of fuel required to produce a given amount of electricity. The total natural gas demand for power generation in each country ($Ce$) is

$$E^{up,\text{elec}}_{demand,Ce,t} = \sum\nolimits_{Ae\_in\_Ce} E^{up,\text{elec}}_{demand,Ae,t}. \quad \text{(Eq. 103)}$$

The demand from any integrated power generation projects with designated natural gas sources are not included in this calculation, as these types of projects are handled separately.

The total Shell gas production, total demand from all Shell facilities, and the portion of supply allocated to electricity generation is determined by country as per the upstream production allocation exercise described previously in Section 2.2.4 and Appendix 2. The natural gas demand for non-integrated electricity production is assumed to be first filled by Shell-produced natural gas allocated to electricity generation, with any deficit being made up by 3rd party natural gas production. The fraction of Shell-produced to 3rd party produced supply is

$$Share^{up,elec}_{supply,Ce,t} = \begin{bmatrix} 1, & if\ V^{up}_{supply,Ce,t} \geq V^{up}_{demand,Ce,t} \\ V^{up}_{supply,Cu,t} / V^{up}_{demand,Ce,t} & if\ V^{up}_{supply,Ce,t} < V^{up}_{demand,Ce,t} \end{bmatrix}_{Cu=Ce} \quad \text{(Eq. 104)}$$

where $V^{up}_{supply,Cu,t}$ is the upstream production and $V^{up}_{demand,Cu,t}$ is the in-country demand from all Shell facilities (LNG, GTL, power generation), excluding projects with designated upstream supply.

The upstream intensity associated with the varied supply sources per country becomes

$$CI^{up,elec}_{Ae,t} = \left(CI^{up,elec}_{Cu,t} * Share^{up,elec}_{supply,Ce,t}\right) + \left(CI^{\overline{up},elec}_{Cu,t} * \left[1 - Share^{up,elec}_{supply,Ce,t}\right]\right) \quad \text{(Eq. 105)}$$

where $CI^{up,elec}_{Cu,t}$ is the country average upstream intensity of Shell-produced gas, and $CI^{\overline{up},elec}_{Cu,t}$ is the country average upstream intensity of 3rd party produced gas. It assumed that the same ratio of Shell- to 3rd party produced gas is used for all non-integrated power generation assets.

Local Fuel Transportation

The emission intensity associated with transporting natural gas by pipeline to electricity generation assets ($Ae$) is estimated by

$$CI_{Ae}^{pipe,elec} = CI_{pipe/d,gas} * D_{(Cu,Ae)}^{pipe,elec} \quad \text{(Eq. 106)}$$

where $D_{(Cu,Ae)}^{pipe,elec}$ is the country average length of pipeline and $CI_{pipe/d,gas}$is the pipeline emission factor for transporting natural gas per unit distance.

Electricity Generation

The intensity associated with generating electricity for each asset with Shell-equity ($CI_{elec,Ae,t}^{gen,elec}$) is calculated from the reported emissions ($GHG_{Ae,t}^{elec}$) and power generation ($E_{elec,Ae,t}^{gen,\text{elec}}$).

Distribution

The fraction of the total generated power lost during transmission between the asset and the point of delivery to a customer ($TR^{dist,elec}$) is used to adjust emission intensities and electricity volumes from point of generation to delivery to end-users. The fraction is input to the calculation. Due to data availability limitations this is assumed to be zero for Shell assets.

Lifecycle Intensity per Asset

The lifecycle intensity for each electricity generation asset (power plant) is calculated by

$$CI_{plant,elec,Ae,t}^{WtW,elec} = \left[ \left[ CI_{Ae,t}^{up,elec} * \left(1 + GR_{Ae}^{pipe,elec}\right) + CI_{Ae}^{pipe,elec} \right] * \frac{GF_{Ae,t}^{elec}}{PE_{Ae,t}} + CI_{Ae,t}^{gen,elec} \right] * \left(1 + TR^{dist,elec}\right)$$

(Eq. 107)

where $plant$ is used to denote power plant generation and the $elec$ subscript is used to indicate that the intensity is represented in terms of electrical energy. Given that the transmission loss is assumed to be zero, the lifecycle intensity reduces to

$$CI_{plant,elec,Ae,t}^{WtW,elec} = \left[ CI_{Ae,t}^{up,elec} * \left(1 + GR_{Ae}^{pipe,elec}\right) + CI_{Ae}^{pipe,elec} \right] * \frac{GF_{Ae,t}^{elec}}{PE_{Ae,t}} + CI_{Ae,t}^{gen,elec} \quad \text{(Eq. 108)}$$

Plant generation data ($E_{plant,elec,Ae,t}^{gen,\text{elec}}$) is used to estimate the amount of electrical energy provided to customers

$$E_{plant,elec,Ae,t}^{end\_use,\text{elec}} = \frac{E_{plant,elec,Ae,t}^{gen,\text{elec}}}{\left(1+TR^{dist,elec}\right)}. \quad \text{(Eq. 109)}$$

where the $elec$ subscript denotes electrical energy.

Lifecycle Intensity of all Shell-produced Thermal Electricity Generation

The aggregated WtW intensity and energy delivered to customers from all Shell gas fired generation assets is calculated by

$$CI_{plant,elec,t}^{WtW,\text{elec}} = \frac{\sum_{Ae}\left(CI_{plant,elec,Ae,t}^{WtW,\text{elec}} * E_{plant,elec,Ae,t}^{end\_use,\text{elec}}\right)}{\sum_{Ae} E_{plant,elec,Ae,t}^{end\_use,\text{elec}}} \quad \text{(Eq. 110)}$$

and

$$E_{plant,elec,t}^{end\_use,\text{elec}} = \sum_{Ae} E_{plant,elec,Ae,t}^{end\_use,\text{elec}}. \qquad \text{(Eq. 111).}$$

### Shell Renewable Electricity Generation

Shell currently has equity in wind and solar renewable energy assets. The operational emission intensity for wind and solar power generation is assumed to be constant over time and by location ($CI_{wind,elec,t}^{WtT,\text{elec}}, CI_{solar,elec,t}^{WtT,\text{elec}}$) and is taken from publicly available data [31].

Shell renewable electricity generation volumes are provided from Shell reporting channels ($E_{wind,elec,t}^{gen,\text{elec}}, E_{solar,elec,t}^{gen,\text{elec}}$). The generation volumes are assumed to be equivalent to the power delivered to customers ($E_{wind,elec,t}^{gen,\text{elec}} = E_{wind,elec,t}^{end\_use,\text{elec}}, \; E_{solar,elec,t}^{gen,\text{elec}} = E_{solar,elec,t}^{end\_use,\text{elec}}$) and transmission losses are currently assumed to be zero.

## 8.4.2. 3rd party generation

### Lifecycle Intensity per market

Grid electricity sales ($E_{grid,elec,Re,t}^{\overline{sales},elec}$) by market ($Re$) are calculated from total electricity sales ($E_{elec,Re,t}^{\overline{sales},elec}$), sales of electricity sourced through PPAs ($E_{PPA,elec,Re,t}^{\overline{sales},elec}$), and sales of renewable power ($E_{REC,elec,Re,t}^{\overline{sales},elec}$) by

$$E_{grid,elec,Re,t}^{\overline{sales},elec} = E_{elec,Re,t}^{\overline{sales},elec} - E_{PPA,elec,Re,t}^{\overline{sales},elec} - E_{REC,elec,Re,t}^{\overline{sales},elec}. \qquad \text{(Eq. 112)}$$

It is assumed that the sales are equivalent to the amount of electricity delivered to customers ($E_{grid,elec,Re,t}^{\overline{sales},elec} = E_{grid,elec,Re,t}^{\overline{end\_use},elec}, \quad E_{PPA,elec,Re,t}^{\overline{sales},elec} = E_{PPA,elec,Re,t}^{\overline{end\_use},elec}, \; E_{REC,elec,Re,t}^{\overline{sales},elec} = E_{REC,elec,Re,t}^{\overline{end\_use},elec}$), assuming negligible (zero) transmission losses.

The lifecycle emission intensities for sales of renewable power ($CI_{REC,Re,t}^{\overline{WTW},\text{elec}}$) and power sourced through PPAs ($CI_{PPA,Re,t}^{\overline{WTW},\text{elec}}$) are calculated on a weighted average basis per market using specific intensities for each generation technology ($CI_{tech,elec,Re,t}$). Sales of grid power are accounted for using a market-specific residual grid intensity ($CI_{grid,elec,Re,t}$), i.e. the average emission intensity of non-renewable power in the market. The weighted average lifecycle carbon intensity by market is

$$CI_{elec,Re,t}^{\overline{WtW},elec} = \frac{\left(CI_{REC,elec,Re,t}^{\overline{WtW},elec} * E_{REC,elec,Rs,t}^{\overline{end\_use},elec}\right) + \left(CI_{PPA,elec,Re,t}^{\overline{WtW},elec} * E_{PPA,elec,Re,t}^{\overline{end\_use},elec}\right) + \left(CI_{grid,elec,Re,t}^{\overline{WtW},elec} * E_{grid,elec,Re,t}^{\overline{end\_use},elec}\right)}{E_{elec,Re,t}^{\overline{end\_use},elec}} \qquad \text{(Eq. 113)}$$

### Lifecycle Intensity of 3rd party Electricity Generation

The aggregated WtW intensity and total energy sales of power produced by 3rd parties and purchased by Shell and resold to end-users is then

$$CI_{elec,t}^{\overline{WtW},\text{elec}} = \frac{\sum_{Re}\left(CI_{elec,Re,t}^{\overline{WtW},\text{elec}} * E_{elec,Re,t}^{\overline{end\_use},\text{elec}}\right)}{\sum_{Re} E_{elec,Re,t}^{\overline{end\_use},\text{elec}}} \qquad \text{(Eq. 114)}$$

and

$$E_{elec,t}^{\overline{end\_use},\text{elec}} = \sum_{Re} E_{elec,Re,t}^{\overline{end\_use},\text{elec}}. \qquad \text{(Eq. 115)}$$

### 8.4.3. Shell's Total Electricity Portfolio

The final portfolio level WtW intensity is

$$CI_{port,\mathrm{elec},t}^{WtW,\mathrm{elec}} = \frac{\left(CI_{plant,elec,t}^{WtW,elec} * E_{plant,elec,t}^{end\_use,elec}\right) + \left(CI_{solar,elec,t}^{WtW,elec} * E_{solar,elec,t}^{end\_use,elec}\right) + \left(CI_{wind,elec,t}^{WtW,elec} * E_{wind,elec,t}^{end\_use,elec}\right) + \left(CI_{elec,t}^{\overline{WtW},elec} * E_{elec,t}^{\overline{end\_use},elec}\right)}{E_{plant,elec,t}^{end\_use,\mathrm{elec}} + E_{solar,elec,t}^{end\_use,\mathrm{elec}} + E_{wind,elec,t}^{end\_use,\mathrm{elec}} + E_{elec,t}^{\overline{end\_use},\mathrm{elec}}}$$

(Eq. 116)

and the total electricity delivered to end-users is

$$E_{port,\mathrm{elec},t}^{\_use,\mathrm{elec}} = E_{plant,elec,t}^{end\_use,\mathrm{elec}} + E_{solar,elec,t}^{end\_use,\mathrm{elec}} + E_{wind,elec,t}^{end\_use,\mathrm{elec}} + E_{elec,t}^{\overline{end\_use},elec}. \quad \text{(Eq. 117)}$$

The resulting lifecycle intensity and electricity are adjusted to a fossil- equivalence basis by

$$E_{port,t}^{sales,\mathrm{elec}} = \frac{E_{port,elec,t}^{sales,\mathrm{elec}}}{PE_{\mathrm{t}}} \quad \text{(Eq. 118)}$$

and,

$$CI_{port,t}^{WtW,\mathrm{elec}} = CI_{port,elec,t}^{WtW,elec} * PE_{\mathrm{t}} \quad \text{(Eq. 119)}$$

where $PE_t$ is a time-varying power efficiency ratio.

# 9. Portfolio Carbon Intensity

## 9.1. Overview / Methodology

The carbon intensity of Shell's energy product sales is the average emission intensity of all the principal energy pathways weighted by the final energy delivered to the customer.

## 9.2. Input Data Sources and Preparation

The inputs to the calculation of the portfolio carbon intensity are the lifecycle intensities and total energy delivered to customers for each pathway, which are estimated in the NCF model according to the calculations outlined in the previous sections.

## 9.3. Calculation Overview

The lifecycle intensity for Shell's total energy product sales is the weighted average of the WtT intensity of each principal energy pathway ($pathway$). It is calculated by

$$CI_{Port,t}^{WtW} = \frac{\sum_{pathway}\left(CI_{port,t}^{WtW,pathway} * E_{port,t}^{end\_use,pathway}\right)}{\sum_{pathway} E_{port,t}^{end\_use,pathway}} \quad \text{(Eq. 120)}$$

where $CI_{port,t}^{WtW,pathway}$ is the lifecycle intensity by pathway and $E_{port,t}^{end\_use,pathway}$ is energy delivered (sold) by pathway. The total volume of energy delivered to customers is

$$E_{Port,t}^{end\_use} = \sum_{pathway} E_{port,t}^{end\_use,pathway} \quad \text{(Eq. 121)}$$

# 10. Carbon credits

Carbon credits are not accounted for in any of the individual energy pathways. Accordingly, Shell's portfolio intensity ($CI_{Port,t}^{WtW}$) is adjusted to account for the use of carbon credits to offset emissions associated with the production and/or use of energy products sold by Shell. The total volume of carbon credits retired are sourced from Shell reporting channels.

Adjustments are made to Shell's energy product portfolio intensity ($CI_{Port,t}^{WtW}$) by

$$NCI_{Port,t}^{WtW} = \frac{\left(CI_{Port,t}^{WtW} * E_{Port,t}^{end\_use}\right) - GHG_t^{offset}}{E_{Port,t}^{end\_use}} \quad \text{(Eq. 122)}$$

where $E_{Port,t}^{end\_use}$ is the total volume of energy delivered to customers and $GHG$ refers to the volume of emissions offset. This value ($NCI_{Port,t}^{WtW}$) is Shell's reported NCI.

# Appendix 1. Abbreviations

| | |
|---|---|
| API | American Petroleum Institute |
| bbl | Barrel of Oil (a unit of volume) |
| boe | Barrel of Oil Equivalent (a unit of energy) |
| CCS | Carbon Capture and Storage |
| CI | Carbon Intensity |
| $CO_2e$ | Carbon dioxide equivalent emissions |
| DOE | United States of America Department of Energy |
| EPA | United States of America Environmental Protection Agency |
| EIA | United States of America Energy Information Administration |
| FAME | Fatty Acid Methyl Esters (biodiesel) |
| GHG | Greenhouse Gases |
| GREET | the Greenhouse gases, Regulated Emissions, and Energy use in Technologies model |
| GTL | Gas to Liquids |
| IEA | International Energy Agency |
| IPIECA | International Petroleum Industry Environmental Conservation Association |
| JEC | Joint Research Centre (JRC) – EUCAR - CONCAWE collaboration |
| LHV | Lower Heating Value |
| LNG | Liquified Natural Gas |
| LPG | Liquified Petroleum Gas |
| LUC | Land Use Change |
| MDO | Marine Diesel Oil |
| MDS | Middle Distillate Synthesis |
| NBS | Nature Based Solutions |
| NCF | Net Carbon Footprint |
| NCI | Net Carbon Intensity |
| NETL | National Energy Technology Laboratory, U.S. Department of Energy |
| NG | Natural Gas |
| OPGEE | Oil Production Greenhouse Gas Emissions Estimator |
| PPA | power purchase agreements |
| RFS | United States of America Renewable Fuel Standard |
| WtG | Well-to-Gate |
| WtLA | Well-to-Loading Arm |
| WtT | Well-to-Tank |
| WtW | Well-to-Wheel or Well-to-Wire depending on the energy pathway |

# Appendix 2. Gas Balance Calculation

Upstream natural gas production is assumed to be routed for use in LNG, GTL, and power generation facilities or delivered directly to customers via pipeline transportation (pipeline gas). The total production and emissions are allocated to the different assets by completing the following gas balance exercise.

Natural gas production volumes (V) by asset country ($Au$) are an input into the calculations. . Shell's natural gas production in each country ($Cu$) is

$$V^{up}_{supply,Cu,t} = \sum_{Au\_in\_Cu} V^{up}_{prod\_gas,Au,\mathrm{Cu},t} \quad \text{(Eq. 123)}$$

where $V^{up}_{prod\_gas,Au,\mathrm{Cu},t}$ is the volume of gas produced by assets ($Cu$) in the country.

The demand for upstream ($up$) gas from each Shell LNG asset ($Al$) in country ($Cl$) is calculated by

$$V^{up,LNG}_{demand,Al,\mathrm{Cl},t} = V^{LNG,LNG}_{Al,\mathrm{Cl},t} * \left(1 + GC^{liq,LNG}_{gas,Al,t}\right) \quad \text{(Eq. 124)}$$

where $V^{LNG,LNG}_{Al,\mathrm{Cl},t}$ is the LNG facility production (outturn). The gas consumption $GC^{liq,LNG}_{gas,Al,t}$ is the ratio of natural gas consumed to run operations to the total LNG outturn. The total demand from LNG facilities by country ($Cl$) is calculated by summing the demand of individual LNG facilities ($Al$) in each country,

$$V^{up,LNG}_{demand,Cl,t} = \sum_{Al\_in\_Cl} V^{up,LNG}_{,Al,\mathrm{Cl},t}. \quad \text{(Eq. 125)}$$

Similarly, the demand from each GTL production asset ($Ag$) with Shell-equity is

$$V^{up,GTL}_{demand,Ag,\mathrm{Cg},t} = V^{MDS,GTL}_{demand,Ag,\mathrm{Cg},t} * \left(1 + GC^{GTL}_{gas,Ag,t}\right) \quad \text{(Eq. 126)}$$

where $V^{MDS,GTL}_{Ag,\mathrm{Cg},t}$ is the GTL facility outturn. $GC^{GTL}_{gas,Ag,t}$ is the ratio of natural gas consumed to run operations to GTL outturn. The total demand from GTL facilities by country ($Cg$) is calculated by summing the demand of individual GTL facilities ($Ag$) in each country,

$$V^{up,GTL}_{demand,Cg,t} = \sum_{Ag\_in\_Cg} V^{up,GTL}_{demand,Ag,\mathrm{Cg},t}. \quad \text{(Eq. 127)}$$

The demand for gas for each Shell electricity generation asset ($Ae$) is calculated from the amount of power generated ($E^{gen,elec}_{elec,Ae,\mathrm{Ce},t}$), where the $elec$ subscript denotes the electrical energy and the $gen$ superscript is used to indicate that the volume is at the power generation stage in the lifecycle pathway. Electrical capacity is converted into a fossil fuel equivalent volume by

$$V^{up,elec}_{demand,Ae,\mathrm{Ce},t} = \frac{E^{gen,elec}_{elec,\mathrm{Ce},t} * \mathrm{CF}_{(E,V)} * GF^{elec}_{Ae,t}}{PE_{Ae,t}} \quad \text{(Eq. 128)}$$

where $GF^{elec}_{Ae,t}$ is the percentage of total fuel intake that is natural gas, $PE_{Ae,t}$ is the power efficiency factor describing the electricity produced from fuel input ($E_{elec}/E_{fuel}$), and $\mathrm{CF}_{(E,V),gas}$ is the energy content of natural gas. The total natural gas demand for electricity generation by country ($Ce$) is then calculated by summing the demand of individual electric facilities ($Ap$) in each country,

$$V^{up,elec}_{demand,Ce,t} = \sum_{Ae\_in\_Ce} V^{up,elec}_{demand,Ae,\mathrm{Ce},t}. \quad \text{(Eq. 129)}$$

The total demand for gas production in country from all Shell facilities is then calculated by

$$V^{up}_{demand,Cu,t} = (V^{up,LNG}_{demand,Cl,t} + V^{up,GTL}_{demand,Cg,t} + V^{up,elec}_{demand,Ce,t})\big|_{Cl,Cg,Ce=Cu} \quad \text{(Eq. 130)}$$

The volume of upstream gas allocated to each of the principal pathways is then calculated by:

- If there is enough Shell supply to meet all in-country demand ($V^{up}_{supply,Cu,t} \geq V^{up}_{demand,Cu,t}$) and the country is not designated an LNG export country,

$$\begin{aligned} V^{up,LNG}_{supply,Cu,t} &= V^{up,LNG}_{demand,Cl,t}\big|_{Cl=Cu} \\ V^{up,GTL}_{supply,Cu,t} &= V^{up,GTL}_{demand,Cg,t}\big|_{Cg=Cu} \\ V^{up,elec}_{supply,Cu,t} &= V^{up,elec}_{demand,Cp,t}\big|_{Cp=Cu} \\ V^{up,gas}_{supply,Cu,t} &= V^{up}_{supply,Cu,t} - (V^{up,LNG}_{demand,Cl,t} + V^{up,GTL}_{demand,Cg,t} + V^{up,elec}_{demand,Cp,t})\big|_{Cl,Cg,Cp=Cu} \end{aligned} \quad \text{(Eq. 131)}$$

  where the volume of natural gas routed to pipeline ($V^{up,gas}_{supply,Cu,t}$) is the surplus gas after meeting the demand from LNG, GTL and electricity production.

- If there is enough Shell supply to meet all in-country demand ($V^{up}_{supply,Cu,t} \geq V^{up}_{demand,Cu,t}$) and the country is designated an LNG export country,

$$\begin{aligned} V^{up,LNG}_{supply,Cu,t} &= V^{up,LNG}_{demand,Cl,t}\big|_{Cl=Cu} \\ V^{up,GTL}_{supply,Cu,t} &= V^{up,GTL}_{demand,Cg,t}\big|_{Cg=Cu} \\ V^{up,elec}_{supply,Cu,t} &= V^{up,elec}_{demand,Cp,t}\big|_{Cp=Cu} \\ V^{up,gas}_{supply,Cu,t} &= 0 \end{aligned} \quad \text{(Eq. 132)}$$

- If there is not enough Shell supply to meet all in-country demand ($V^{up}_{supply,Cu,t} < V^{up}_{demand,Cu,t}$), the available supply is allocated proportionally according to each asset's demand by

$$\begin{aligned} V^{up,LNG}_{supply,Cu,t} &= \left[V^{up,LNG}_{demand,Cl,t} * \frac{V^{up,LNG}_{demand,Cl,t}}{V^{up}_{demand,Cu,t}}\right]_{Cl=Cu} \\ V^{up,GTL}_{supply,Cu,t} &= \left[V^{up,GTL}_{demand,Cg,t} * \frac{V^{up,GTL}_{demand,Cg,t}}{V^{up}_{demand,Cu,t}}\right]_{Cg=Cu} \\ V^{up,elec}_{supply,Cu,t} &= \left[V^{up,elec}_{demand,Cp,t} * \frac{V^{up,elec}_{demand,Cp,t}}{V^{up}_{demand,Cu,t}}\right]_{Cp=Cu} \\ V^{up,gas}_{supply,Cu,t} &= 0 \end{aligned} \quad \text{(Eq. 133)}$$

- If there is no Shell supply to meet in-country demand ($V^{up}_{supply,Cu,t} = 0$),

$$\begin{aligned} V^{up,LNG}_{supply,Cu,t} &= 0 \\ V^{up,GTL}_{supply,Cu,t} &= 0 \\ V^{up,elec}_{supply,Cu,t} &= 0 \\ V^{up,gas}_{supply,Cu,t} &= 0 \end{aligned} \quad \text{(Eq. 134)}$$

where the volume allocated is weighted by the fraction of total demand of each principal pathway.

It should be noted that the gas balance does not include natural gas production supply dedicated to integrated LNG and GTL assets. These volumes are handled separately in the NCI calculation.

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