Attributional vs. Consequential LCA

Methodology Overview, Review and Recommendations with focus on Well-to-Tank and Well-to-Wheel Assessments

Study commissioned by EUCAR to IFP Energies Nouvelles and Sphera

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Main report

Background

Managing and mitigating the effects of climate change has become one of the highest priority topics for governments, industry and - in general - society over the recent years. Subsequent to the Paris Agreement in 2015, the European Commission presented the European Green Deal in 2019 with the aim of a climate neutral Europe by 2050. Many companies in the Energy & Mobility sectors, including many automotive and oil & gas companies, are pursuing this target and have defined and published their decarbonization strategies and policies.

In this context, quantifying the Greenhouse Gas (GHG) intensity - also called carbon footprint - in an appropriate manner is of growing critical concern to achieve transparency in the supply chain, to develop suitable emission mitigation strategies and hence to support decarbonisation target(s).

Life Cycle Assessment (LCA) offers an established and globally standardized methodology to help quantify the potential environmental impact of products, processes, and services along the supply chain by following ISO 14040/44.

The European Commission has identified the strategic and practical value of LCA and implemented several approaches, guidelines and tools to support the application of LCA. For instance, the European Commission Joint Research Centre (JRC) developed the “International Reference Life Cycle Data System (ILCD)” and its related ILCD-Handbook[1], a detailed guidance document for LCA practitioners, which is highly accepted in the LCA community and widely used. The ILCD-Handbook, in conjunction with the ISO 14040/44 standards, can be seen as internationally accepted and applied reference documents for LCA.

Within the EU initiative “Single Market for Green Products”, the European Commission (DG JRC and DG Environment) also developed and launched the Product Environmental Footprint and Organisational Environmental Footprint (PEF/OEF) methodology, which is based on Life Cycle Assessment and utilizes the ILCD data reference system. The goal of the EF methodologies is to provide a common way of measuring environmental performance” for companies within in the EU wishing to market their product. The methodology has been field tested in a pilot phase until 2019 and is now in the transition phase towards its implementation in the upcoming years.

As mentioned, especially in the Energy & Mobility area with the potential technology transition from combustion engines to alternative drivetrains such as battery electric and fuel cell electric vehicles, an accurate quantification of the carbon footprint is key to fulfil the set quotas and actively contribute to the GHG emission reduction target.

JEC (JRC-EUCAR-CONCAWE) is a long-standing collaboration between the European Commission's Joint Research Centre, EUCAR and CONCAWE, in order to:

- Evaluate the energy use and GHG emissions related to engine and vehicle technologies, fuel qualities, and the interaction between them.
- Coordinate and co-operative research on the evaluation of the relative performance of future road transport fuels and powertrains.
- Support the sustainability roadmap of the European vehicle and oil & gas industries and provide the European Commission with scientific facts.

[1] European Commission - Joint Research Centre - Institute for Environment and Sustainability: International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition March 2010. EUR 24708 EN. Luxembourg. Publications Office of the European Union; 2010

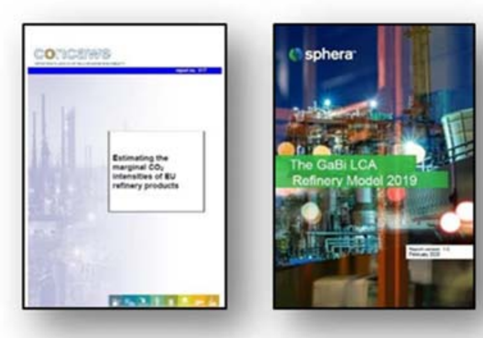
The reference work of the JEC collaboration is the so-called Well-to-Wheels study, assessing the energy use and GHG emissions of road fuel and powertrain configurations in Europe today and in 2030. Currently, an update of the Well-to-Tank and Wheel-to-Wheel data for different fuels is conducted and will be published in 2020 as version v5.

Purpose

Over the years the classical attributional LCA was supplemented by an alternative way to model LCA systems: the consequential LCA modelling principle. Despite the fact that the goal & scope, method and required data under both principles clearly differ, there has been a controversy between different industries, LCA experts, stakeholders and between practices of the automotive and petroleum/ refining industry regarding the use of “consequential” or “attributional” data.

Therefore, **EUCAR commissioned IFPEN and SPHERA to give a methodology overview of consequential and attributional LCA modelling principles, and explain differences in the intended goal, application and explore implications for GHG inventories for LCA studies like the Well-to-Wheels study)**. The review of existing fuel datasets included inventories calculated by CONCAWE following the consequential modelling principle and SPHERA’s inventories following an attributional modelling principle. Key findings are summarized, and the analysis concludes with recommendations for the proper usage of the data.

Objectives



The study is divided into three main tasks:

- Review of CONCAWE’s refinery model and its accompanying documentation with regard to scientific validity and plausibility.
- Review of SPHERA’s GaBi LCA refinery model and its accompanying documentation with regard to scientific validity and plausibility.
- Summary report including methodology overview, key findings, conclusion and recommendations on how to derive representative GHG inventories for fuels and vehicles in a given goal & scope.

Note that the reviews of the two refinery models and the accompanying documentation are solely performed by IFPEN. They do not constitute a formal critical review in accordance with ISO standard 14040, but focus on technical content, scientific validity, and consistency. A full validation of all primary data, databases and models were outside the scope of this review, but spot checks and plausibility checks are performed as indicated.

Details of the review are explained in the corresponding Annexes. The summary report was collectively developed by IFPEN and SPHERA.

Methodology

The modelling principle descriptions are taken from the European Commission's ILCD-Handbook and supplemented with some comments and explanations. Please note that the descriptions are of general nature and do not necessarily reflect all complexities of the analysed CONCAWE and SPHERA refinery models. For details on the models, see the related Annexes.

Attributional Modelling Principle [taken from the ILCD-Handbook, 2010]

"The attributional life cycle inventory modelling principle is also referred to as "accounting", "book-keeping", "retrospective[2]", or "descriptive" (or sometimes and potentially confusing: "average" or "non-marginal").

It depicts the potential environmental impacts that can be attributed to a system (e.g. a product) over its life cycle, i.e. upstream along the supply-chain and downstream following the system's use and end-of-life value chain.

Attributional modelling makes use of historical, fact-based, measurable data of known (or at least know-able) uncertainty and includes all the processes that are identified to relevantly contribute to the system being studied. In attributional modelling the system is hence modelled as it is or was (or is forecasted to be[3]). This also applies to its background processes: As background data, producer-specific LCI data is ideally used where specific producers provide a background good or service (e.g. a single tier-two supplier is producing the required bricks for a large office building).

Average or generic data is typically used where the goods and services stem from a wide mix of producers or technologies (e.g. for electricity consumed by a consumer product in Austria the Austrian consumption mix of electricity with the actual quantitative share of power plants using hydro-power, natural gas, hard coal, fuel-oil, nuclear power, biomass, etc. would be used, including the specific electricity imports and exports to/from the Austrian market).

The change from specific to average or generic data is only done for practicality reasons and is a simplification that is justified from the averaging effect that typically occurs several steps up and down the supply-chain and value chain." [taken from ILCD-Handbook, 2010]

Attributional modelling is the LCA modelling framework that inventories the inputs and output flows of all processes of a system as they occur for a specified reference period based on historical data. Modelling processes along an existing supply chain is of this type. The attributional approach is therefore applied in situations where:

- the focus of the study is on a clearly defined functional unit and its corresponding product system, i.e., the totality of those activities that are necessary to provide the functional unit. The expansion of the system boundary beyond what is required to provide the defined functional unit is to be avoided as the main goal is to assess the options related to the product system under study as such (rather than the effects of marginal changes in supply of one product on competing products and the larger background system).
- variations in results are to be caused and explained by technical differences between product systems rather than by potential economic market reactions in the future.

[2] Even if older literature is referring attributional LCA as a "retrospective" approach, it does not imply that attributional LCA is not able to be used prospectively. Prospective approaches based on technical parameters and prospective settings concerning future developments are well established and done regularly. The prospective approaches make use of retrospective (real, measurable) information to get to realistic future results.

[3] See above „prospective attributional approach"

- not all background processes can be traced back to specific suppliers, either retrospectively due to supply via “stock/resource” markets or prospectively if a potential future supplier of a material is not yet known.

Most studies in industry and research are based on attributional LCA (A-LCA), on the own “product” (responsibility) and its related supply chain in a micro-economic perspective.

Consequential Modelling Principle [taken from the ILCD-Handbook, 2010]

“The consequential life cycle inventory modelling principle is also called “change-oriented”, "effect-oriented", "decision-based", “market-based” and (older and incompletely / misleadingly capturing the issue: “marginal” or “prospective”).

It aims at identifying the consequences that a decision in the foreground system has for other processes and systems of the economy, both in the analysed system's background system and on other systems. It models the analysed system around these consequences.

The consequential life cycle model is hence not reflecting the actual (or forecasted) specific or average supply-chain, but a hypothetic generic supply-chain is modelled that is prognosticated along market-mechanisms, and potentially including political interactions and consumer behaviour changes.

To better reflect market constraints and supplier-related explicit decisions, some researchers constrain the market-mechanism models by explicitly considering existing supply contracts and planned future suppliers. Other constraints in use are existing or expected policy measures such as e.g. green taxes / incentives and material bans.

A key step in consequential modelling is the identification of the marginal processes, i.e. the generic supply-chain, starting from the decision and building the process chain life cycle model around it (…). Some experts identify each one single marginal process, others identify a combination of several of the most likely marginal processes to have a more robust estimate. A wide range of mechanisms is discussed among LCA practitioners, how a decision affects other processes and products, and which type of consequences follow: these mechanisms range from causing the need to build new production plants for additionally required materials, parts, etc. (or taking plants out of operation), to market displacement of competing products, consumer behaviour changes, and the like. Secondary consequences may counteract the primary consequences (then called 'rebound effects') or further enhance the preceding consequence.

Regarding modelling the main market consequences, components of general (and in some cases partial) equilibrium models are employed. Central in modelling market consequences is a quantitative understanding of the markets and how direct and indirect changes in supply and demand of the analysed good or service act in the markets to cause specific changes in demand and supply of other goods and services.” [taken from ILCD-Handbook, 2010]

Consequential modelling is mostly applied by LCA researchers, industry experts or policy makers in a macro-economic decision context as the LCI modelling principle identifies and models all processes in the background system of a system in consequence of decisions made in the foreground system.

The table below shows an overview of the two modelling principles.

Modelling Principles – Overview

Topic	Attributional Modelling	Consequential Modelling
Definition [ILCD-Handbook, 2010]	LCI modelling principle that inventories the inputs and output flows of all processes of a system as they occur. Modelling process along an existing supply chain is of this type	LCI modelling principle that identifies, and models all processes in the background system of a product system in consequence of decisions made in the foreground system
Goal	Analysis of an average operation (e.g. on an annual basis)	Analysis of changes in operation (e.g. changes in demand)
Explanation	Describes the potential environmental impacts that can be attributed to a particular product system in retrospective fashion	Describes the potential environmental impacts induced by the marginal increase in product supply in the greater economic system that surrounds it. For example, in a consequential LCA of biofuels, one might consider how changes in land use for energy crop cultivation in one region will lead to changes in land use in other regions (i.e., indirect land use change)
Guiding question	For example, what are the potential environmental impacts of the average production of 1 litre of diesel fuel (under different technical conditions)?	For example, what are the potential environmental impacts of a decrease in fossil diesel demand due to the increase of the use of alternative fuels in the transport sector?
Approach	Assigns elementary flows and potential environmental impacts to a specific product system typically as an account of the history of the product. Can use scenario analysis to project future technical situations	Studies the environmental consequences of possible (future) changes between within one or between multiple product systems
Users	LCA practitioners from all industry sectors (e.g. using petroleum products) or policy makers being interested in quantifying and improving products based on average operations	Researcher and industry experts or policy makers being interested in quantifying changes and improving products due to market changes or constraints

Application / Context [ILCD-Handbook 2010]	Development of a carbon footprint or LCA for a specific product Hot-spot and weak point analysis of a specific product Comparison of specific goods or services Development of life cycle-based Type I Ecolabel criteria Development of Product Category Rules (PCR) Development of a life cycle-based Type III environmental declaration (e.g. Environmental Product Declaration (EPD)) Greening the supply chain	Policy development: Change analysis, forecasting and analysis of the environmental impact of pervasive technologies, raw material strategies, etc. and related policy development Policy information: Identifying product groups with the largest environmental improvement potential
Calculated Result	Average CO2-eq inventory	Marginal CO2-eq inventory
Abundance (est.)	>95% of all LCAs performed (sum of A-LCA + C-LCA)	<5% of all LCAs performed (sum of A-LCA + C-LCA)

Key Findings

The following key findings are observed:

- The attributional as well as the consequential modelling principles are each valid under a differently defined goal & scope and in different decision contexts.
- The attributional approach describes the potential environmental impacts that can be attributed to a product system, on average, for a specified time period. It analyses a specifically defined or average operation, e.g. on an annual basis.
- The consequential approach describes the potential environmental impacts imposed by a marginal change in supply of or demand for a product on the economic system that it is embedded in (like background processes, alternative product supplies and constraints). It analyses the overall effects due to changes in operation, e.g. changes in demand.
- Both refinery models are based on a detailed refining flow chart, including main interconnections and synergies between products, processes and crude oil and other feedstocks; the CONCAWE model seems to be a bit more sophisticated. Both models represent average European refining operations.
- At both refinery models, GHG emissions (CO2-eq) are based on the fuels combusted at the refinery (for heat, steam and electricity generation) and “chemical” CO2, released e.g. at the production of hydrogen (via steam reforming and partial oxidation). The total GHG emissions are attributed to the finished petroleum products.

CONCAWE’s Refinery Model (see Annex 2)

- The CONCAWE refinery model is a linear programming (LP) model, which follows an algorithm to maximize the refinery margin (i.e. minimizing refiner’s costs). In addition to a set of variables (e.g. feedstock spec, output spectrum, output spec) and constraints (e.g. process unit capacities, product demand and qualities, sulphur limitations, calibration limits, etc.), the cost optimization algorithm considers the direct dependencies of these variables.

- As with all intermediate products of the refinery, hydrogen (mainly produced by the catalytic reformer, see Annex 2) is assigned a cost value which leads to its cost-optimal distribution across the hydrogen consuming processes, taking into account a) their respective contribution of each to the product formulation and b) the compliance with the sulphur specifications of these products. The heaviest fractions naturally require more hydrotreatment than the lighter ones. The use of available hydrogen is thus optimized to meet a specific demand for products that comply with their specifications as well as other constraints considered in the LP (crude supply, process capacity, sulphur limitations, etc.).
- The CONCAWE refinery model calculates marginal CO2 intensities induced by a marginal change, e.g. in demand for petroleum products, around the European refinery operations calibrated for the reference year 2010 in terms of refinery configuration, price of crude oil, other feedstocks supply, petroleum product demand and specifications, as well as processing capacities.
- The calibration is constrained by limiting the degree of variations of the LP model variables (crude supply, process load or even product formulation) relative to the observed data of the reference year.
- In the CONCAWE model, the total marginal CO2 emissions are allocated to the finished products by mass on a unit process level. Considering the energy effort required to produce the compounds of finished products at each unit process, the marginal CO2 emissions are allocated to its outputs using a kind of backpack principle. These marginal CO2 intensities therefore represent consequential (i.e., change-induced) emissions compared to the base case (reference year 2010).
- In summary, the CONCAWE refinery model aims to reflect the impact on the refining sector of potential changes that could affect its framework (reduction in crude supply for upstream, new product quality specifications and new environmental regulations for downstream) from a refiner’s point of view. From this, emission standards to be met by producers of alternative fuels in the framework of the JEC’s Well-to-Wheels study, are supposed to be defined.

SPHERA’s Refinery Model (see Annex 3)

- SPHERA's GaBi LCA refinery model is a generic LCA model based on a parameterized linear equation system. It is fully customizable by its user. The expert user himself defines the routing of intermediate flows between processes and to the finished products pools and utility generation, as well as the shares of the latter purchased on the market or produced onsite.
- SPHERA’s GaBi LCA refinery model was developed to calculate the life cycle inventory of petroleum products and it aims to provide attributional environmental values representing the average production of petroleum products in a representative refinery, based on average data.
- At SPHERA’s GaBi LCA refinery model a process by process allocation rule is applied. The model allocates the environmental burden of each unit process to its outputs based on physical quantities. Unit process energy expenditures are allocated by mass, the crude oil and subsequent hydrocarbon demand is allocated by its energy content on a pro rata basis. Hence, each finished product carries its individual emissions backpack accumulated on its way through the refinery (backpack principle, that depends on the amount and energy intensity of the conversion steps necessary for each product).

- Following these rules, most of the CO2-eq associated with the energy usage of the catalytic reformer is allocated to the reformate intended for gasoline due to its high yield (around 90% by mass) compared to its co-products. For comparison, hydrogen is around 3% by mass.
- The allocation procedure applied in SPHERA's GaBi LCA refinery model is line with ISO 14044 step 2, partitioning inputs and outputs among co-products. It is also in line with current practice of the LCA community which favours physical criteria for allocation.
- It is important to emphasize that there is no single way to allocate emissions in LCA. CONCAWE made a choice different to the one made by SPHERA. However, both approaches are "correct" in that they are technically and scientifically valid, reasonable, and avoid double counting any of the emissions.
- Both models allocate on a process-by-process level which is deemed necessary to reflect the complexity of a refinery and the fact that different products are subject to a different number and type of process steps. Allocation on a process-by-process level therefore renders more accurate results than allocation on a refinery level.
- SPHERA's GaBi LCA refinery model calculates the emission inventories in an "accounting" or "descriptive" fashion for an average operation, without assigning a higher relevance to certain processes or products, such as hydrogen from the catalytic reforming unit.

Refinery Gate-to-Gate CO2-eq. Emissions

In the following table the European refinery gate-togate GHG emissions in g CO2 equivalent (CO2-eq) per MJ of fuel are shown for the CONCAWE as well as SPHERA refinery model. The values in the table are based on IPCC characterisation factors taken the 2007 4th Assessment Report (AR[4]) in order to be consistent with the methodology used in the JEC-WtW studies.

The shown CONCAWE values refer to the draft JEC-WtW study version 5, provided by EUCAR to SPHERA and IFPEN. SPHERA's values refer to the GaBi databases 2020.

All figures shown in the table refer to the delivery of 1 MJ fuel, at refinery gate.

gCO_{2}-eq/MJ_{fuel} (LHV)	**CONCAWE (JEC-WtW)**	**SPHERA (GaBi databases)**
	Consequential value	*Attributional value*
Gasoline[5]	5.5	9.6
Diesel[6]	7.2	3.4
Jet Fuel	6.1	2.5
Heavy Fuel Oil	-3.7	4.1

Source:

- CONCAWE – Estimating the marginal CO2 intensities of EU refinery products, report No. 1/17, 2017
- SPHERA's GaBi databases 2020

[4] In contrast the modelling of a refinery as unit-process black box (crude oil in → several petroleum products out) is considered inadequate in this goal & scope).
[5] Refers to COG 1 data sheet
[6] Refers to COD 1 data sheet

The CONCAWE values are based on a consequential modelling principle that provides marginal CO2-eq intensities. SPHERA's CO2-eq intensities are based on an attributional approach that provides average values.

Explaining the Difference between CONCAWE and SPHERA's CO2-eq Results

The differences observed in the refinery Gate-to-Gate CO2-eq. intensities of petroleum products supplied by CONCAWE and SPHERA are mainly due to the allocation methods applied.

These depend on the applied modelling principles and, in particular, on how hydrogen from the catalytic reformer (main source of hydrogen and its special role within the refinery according to IFPEN) is treated respectively how the emissions of the catalytic reformer are allocated to reformate and the other product outputs, especially hydrogen.

SPHERA applies the same allocation method to hydrogen as to any other intermediate or refinery product. That means that the inputs and outputs of the catalytic reformer, are allocated to each co-product based on physical properties (mass allocation for the utilities, energy content allocation for the feedstock). According to its yield and LHV ratio, the hydrogen gets approx. 3%m of utilities and 8%energy of its feedstock related CO2-eq. burden allocated. Most of the burdens are allocated to the reformate (around 90% mass-yield) which is ultimately destined for gasoline production.

In the CONCAWE model the central role of hydrogen in refineries is transcribed by the marginal approach of CONCAWE via the applied LP model: The consequential approach assigns a scarcity value based on the hydrotreatment needs of the oil fractions used to provide the desired composition of the finished products, that meet defined sulphur specifications. The scarcity value then governs the cost-optimal routing of the hydrogen towards those processes that produce the products that most need to be hydrotreated to achieve the desired production volumes and sulphur specifications, i.e., more hydrogen is routed towards medium and heavy products like diesel and heavy fuel oil) than towards gasoline.

This explains the inversion of the ranking obtained between the CO2 intensities of fuels calculated by the SPHERA and CONCAWE models: gasoline being higher than diesel in the case of SPHERA, the reverse being obtained by CONCAWE.

As explained in Annex 3, this is due to the fact that the application of a physical allocation to the main hydrogen source-process, can only exempt products requiring more than the average hydrogen treatment from the energy effort required (and hence the CO2 burden induced) in the production of that special product, hydrogen. In other words, diesel and heavy fuel pools in this context benefit from hydrogen without bearing the environmental burden that is allocated to gasoline.

In conclusion, there is no equitable allocation method for the catalytic reformer. Hence, a transparent documentation is key.

Conclusions and Recommendations

The main key conclusions and recommendations of this work are as follows:

- Both modelling principles, attributional and consequential, are scientific sound, none of them is superior, both have its domain of validity and applicability, but each serves a different aim.

- The usage of CO2-eq inventories either calculated following the attributional or consequential modelling principle depends on the specific goal & scope defined and decision context being applied, (see also ISO 14040/44 and European Commission's ILCD Handbook).
- The attributional modelling principle analyses an average operation, e.g., on an annual basis. These CO2-eq inventories are intended to be used by LCA practitioners and users from all industry sectors using petroleum products or policy makers being interested in average GHG emission data based on average operations and, used in micro-economic decision contexts with the core operation and supply chain in focus.
- The consequential modelling principle, analyses impacts due to marginal changes or constraints (most often) implied by the market or a new policy (e.g. changes in diesel demand in comparison to the base year 2010) and its impact on refining operation from a refiner's point of view. It is applied by research, industry and policy makers in a macroeconomic decision context, including effects on the economic system in the background and effects on alternative, avoided or constraint products, that relate to the assessed product in the foreground.
- Since consequential CO2-eq inventories of refined product assess not the absolute level but the variation in CO2-eq emissions that the refinery would exhibit if it had to produce more (or less) of a certain product, starting from a given equilibrium situation, the resulting values shall not be used for any attributional LCA studies.
- In other words, attributional LCA models capture the average CO2-eq to produce diesel or gasoline. Consequential LCA models capture the change in CO2-eq released to deliver more (or less) diesel or gasoline, e.g., due to a new policy motivating the use of alternative fuels in the transport sector.
- The fulfilment of an additivity criterion within the consequential modelling principle (by reattributing process-related emissions) relates to necessities or implications within consequential modelling but does not qualify the results to be used in an attributional context (especially if CO2-eq values for refinery products are negative or zero).
- Special attention must be paid to the case of hydrogen and its major production process in refineries, the catalytic reformer (for details see Annex 3).
- Consequential CO2-eq inventories shall be used in a consequential context.
- Attributional CO2-eq inventories shall be used in an attributional context.
- Following the European Commission's ILCD-Handbook, attributional principles should be used for carbon foot printing, GHG intensity studies, Life Cycle Assessment (LCAs), Environmental Product Declaration (EPDs), etc. interested in quantifying an average operation. The consequential principles should be used in the policy context, especially for change analysis, forecasting and strategy evaluations being interested in quantifying impacts due to (market) changes.
    - attributional LCAs are typically used to provide information on emissions which can be associated with a specific product life cycle. It supports micro-economic decision support related to "product comparison", "comparative assertion", "product advance development", "product development", "product design", "weak point analysis", "product benchmarking" "face-lift", etc.
    - consequential LCAs are typically used for macro-economic decision support or strategy analysis related to "product comparison", "policy development", "concept development", "pervasive technologies", and similar and often in combination with "raw material / energy / XY basis / technology" etc.

Given their consequential nature, the CO2 intensities of the products assessed from CONCAWE's refining cost optimization model are able to capture changes in refinery emissions caused by changes in the refinery production due to, for instance, the implementation of new regulations on the use of alternative fuels in transport. In other words, these marginal CO2-eq intensities of petroleum products can be used within the framework of consequential life cycle analysis (C-LCA) of the refining sector, all the more so as CONCAWE model represents in a detailed and complete way the interconnections between processes and products as well as the constraints in refineries and the key role of hydrogen.

SPHERA's GaBi LCA refinery model enables to be consistent with the current practice of the LCA standards and applications, which favours physical criteria for allocating impacts. Based on the "backpack principle", the process-by-process application of physical factors (mass and energy) allocates the environmental burden of the modelled refinery based on average data and ensures that average CO2-eq intensities are obtained for petroleum products. These results can therefore be used in the framework of attributional life cycle analysis (A-LCA).

If the refinery CO2-eq values are used in the context of whole Well-to-Tank and Wheel-to-Wheels analyses, please keep in mind that upstream data on crude oil or other feedstocks used as well as the fuel conditioning and distribution may also contribute to the differences in overall CO2eq. results.

In summary, CO2-eq inventories from CONCAWE's refinery model as well as SPHERA's GaBi LCA refinery model seems to be scientific sound, plausible and appropriate to be used in its defined goal & scope and decision context. Further improvements potentials for both models are made by IFPEN and are described in the Annexes, especially Annex 4. The CONCAWE values shall be used for any kind of consequential modelling; the SPHERA values shall be used for any attributional modelling.

Recommendation Summary:

Topic	Attributional Modelling	Consequential Modelling
Goal	Analysis of an average operation (e.g. on an annual basis)	Analysis of changes in operation (e.g. changes in demand)
View	"Accounting", "descriptive"	"Change-oriented", "market based"
Usage	To analyse fuel supply chains (Well-to-Tank) and whole vehicle LCAs (Well-to-Wheel) as well as complete carbon cycles even beyond tail pipe emissions.	To analyse changes in refining operations.
Application / Context	Carbon foot printing, GHG intensity studies, Life Cycle Assessment (LCAs), Environmental Product Declaration (EPDs) interested in average operation.	Policy context: Change analysis, forecasting and analysis of the environmental impact, identifying product groups with the largest environmental improvement potential, etc., interested in analysis of changes
Target group	LCA practitioners from all industry sectors using e.g. petroleum products or policy makers being interested in quantifying and improving products based on average operations	Researcher and industry experts or policy makers being interested in quantifying changes and improving products due to market changes or constrains
Calculated Result	Average CO2-eq inventory	Marginal CO2-eq inventory