Methodology for the free allocation of emission allowances in the EU ETS post 2012

Sector report for the refinery industry

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Disclaimer and acknowledgements

Disclaimer

The views expressed in this study represent only the views of the authors and not those of the European Commission. The focus of this study is on preparing a first blueprint of an allocation methodology for free allocation of emission allowances under the EU Emission Trading Scheme for the period 2013 – 2020 for installations in the refinery industry. The report should be read in conjunction with the report on the project approach and general issues. This sector report has been written by Ecofys.

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1 Introduction

In refineries, crude oil is converted via various physical, physical-chemical and chemical processes into different products such as:

- Fuels for transport
- Combustion fuels for the generation of heat and power
- Raw materials for the petrochemical and chemical industries
- Products such as lubricating oils, paraffin and bitumen

Apart from these products, refineries also produce energy as a by-product in the form of heat and/or power.

In order to acquire information and data on the refinery sector, Ecofys has been in contact with the European petroleum industry association (Europia) and the oil companies' European association for the environment, health and safety in refining and distribution (CONCAWE). Europia has 18 members covering over 85% of EU refinery capacity and CONCAWE has 39 members representing essentially all the EU refining capacity (Europia & CONCAWE, 2009d).

Table 1 shows the relevant activity classification of the refining industry. The refinery industry is associated with one category of activities in the amended Annex I to the Greenhouse Gas Emission Allowance Trading Directive[1], which will be referred to as the amended Directive. In the NACE Rev. 1.1, classification of economic activities, the sector is associated with one four-digit code.

Table 1 Classification of the refinery industry in the categories of activities of the Annex I of the amended Directive and in the NACE Rev. 1.1 classification of economic activities

Annex I category of activities	NACE Rev. 1.1 code	Description (NACE Rev. 1.1)
Refining of mineral oil	23.20	Manufacture of refined petroleum products

In May 2009, the Community Independent Transaction Log (CITL) listed 148 open accounts (146 in EU27 and 2 in Norway) that are specified in the original Annex I category of activities as "mineral oil refineries" (CITL, 2009a). Depending on the structure of a refinery and the permit procedure in a country, a single refinery may hold more than one permit. This situation occurs in Belgium, Germany, Italy, Poland, Spain and the UK.

A list of refineries and accounts as provided by Europia & CONCAWE can be found in Appendix A. The list contains 137 open accounts specified "mineral oil refineries" in the

[1] Directive 2009/29/EC amending Directive 2003/87/EC

original Annex I category of activities for EU27. For 11 of these accounts the status is currently under investigation by Europia and CONCAWE. As a preliminary outcome of this investigation, the organizations indicated that 7 of them have probably either been shut down or are no longer operating as a full mineral oil refinery (Europia & CONCAWE, 2009e).

There are two reasons for the discrepancy with CITL: 8 accounts specified in CITL as mineral oil refineries according to Europia & CONCAWE are in fact not refineries (Europia & CONCAWE, 2009b) and one refinery is deemed to have been shut down since it has not reported any emissions since 2007.

In addition to the accounts specified in CITL as mineral oil refineries, Europia & CONCAWE list 10 accounts that are part of the refinery sector but are not specified as such in CITL: 9 of these 10 accounts fall under Annex I category of activities 'combustion of fuels in installations with a total rated thermal input exceeding 20MW (except in installations for the incineration of hazardous or municipal waste)', which from hereon will be denoted as 'combustion of fuel'. The remaining account is considered in CITL to perform an 'Other activity opted-in pursuant to Article 24 of Directive 2003/87/EC'.

The distribution of refineries and accounts over EU27 is shown in Table 2.

Table 2 Distribution of refineries over EU27 according to Europia and CONCAWE (2009a,e) and open accounts (CITL, 2009a) Values in brackets indicate installations where the status still needs to be clarified by Europia & CONCAWE.

Country	No. of refineries	No. of open accounts that according to CITL perform the activity "refining of mineral oil"	No. of refineries that according to CITL perform another activity	Comments regarding differences between list of refineries (Europia and CONCAWE 2009a,e) and CITL
Austria	1	1		
Belgium	4	5		
Bulgaria	1 (+2)	(+2)	1	
Czech Republic	3 (+1)	3 (+1)		
Denmark	2	1	1	
Finland	2	2		
France	14	16		2 accounts are not refineries
Germany	16	29	3	4 accounts are not refineries
Greece	4	4		
Hungary	1 (+2)	1	(+2)	
Ireland	1	1		
Italy	16	21		1 account is not a refinery; 1 installation is deemed to have been shut down

Continuation Table 2

Country	No. of refineries	No. of open accounts that according to CITL perform the activity "refining of mineral oil"	No. of refineries that according to CITL perform another activity	Comments regarding differences between list of refineries (Europia and CONCAWE 2009a,e) and CITL
Lithuania	1	1		
Netherlands	6	6		
Poland	3 (+2)	7 (+2)	2	
Portugal	2	2		
Romania	5 (+4)	5 (+4)		
Slovakia	1	1		
Spain	11	12	1	
Sweden	5	5		
United Kingdom	11	14		1 account is not a refinery
Total	**110 (+11)**	**137 (+9)**	**8 (+2)**	

Table 3 lists the allocated allowances and estimated EU emissions of greenhouse gases (GHGs) from 2005 onwards for the refinery sector as defined in CITL (2009a,b) and according to Europia & CONCAWE (2009e). The emissions associated with the 10 installations, that according to Europia & CONCAWE, are part of the refinery sector but are not specified as such in CITL accounted for 3-5% of the sector`s emissions.

Information on which emissions are included and how they were determined can be found in the guidelines for monitoring and reporting of GHG emissions[2]; in particular Annex III: 'Activity-specific guidelines for mineral oil refineries...'

Table 3 Allocated allowances and estimated EU emissions of greenhouse gasses (GHGs) from 2005 onwards for the refinery sector as defined in CITL (2009a,b) and according to Europia & CONCAWE (2009e); allowances and emissions were taken from CITL (2009a,b)

	Annex I activity 'mineral oil refineries' CITL (2009a,b)		Sector according to Europia & CONCAWE (2009e)	
Year	**Allocated allowances (Mt CO_2 eq.)**	**Verified emissions (Mt CO_2 eq.)**	**Allocated allowances (Mt CO_2 eq.)**	**Verified emissions (Mt CO_2 eq.)**
2005	158.1	150.0	161.7	152.3
2006	157.5	158.5	161.0	151.2
2007	163.3	153.3	166.9	159.1
2008	150.4	152.3	154.2	155.9

[2] Commission Decision 2007/589/EC

Most, if not all refineries produce electricity on-site (Europia & CONCAWE, 2009d). According to the Reference Document on Best Available Techniques for mineral oil refineries (BREF refineries, 2003), CO_2 emissions from power plants in refineries account for about 42% of the CO_2 emitted by a refinery. Europia & CONCAWE (2009d) however indicate that this figure is likely to include the total emissions from electricity and steam in refinery utility plants. According to them, electricity generation alone would account for about 16% of the total refinery CO_2 emissions. Many refineries import electricity leading to indirect emissions, although electricity may be exported as well. Refineries may also import and/or export steam.

2 Production process and GHG emissions

The basic processes in the production of mineral oil products from crude oil can be categorized in the following groups (Öko Institut and Ecofys, 2008; Europia & CONCAWE, 2009d):

- Distillation processes: physical separation methods to decompose homogeneous liquid mixtures under usage of the different boiling behaviour of the mixture components.
- Conversion processes: chemical methods to change the chemical structure of hydrocarbons contained in the different crude oil fractions (mostly producing smaller molecules and increasing the hydrogen to carbon ratio).
- Finishing processes of mineral oil products: the gases, liquefied gases, gasoline, middle distillates and gas oils produced by the distillation and conversion processes are treated to compounds which disturb further processing or the quality of finished products.
- Other processes: besides these basic procedures mentioned above, a number of further procedures are necessary to achieve the desired quality of the mineral oil products and process arising by-products.

In addition to the process steps that are typically found in refineries, several refineries also include petrochemical units for the production of basis chemicals such as steam crackers and units for the production of aromatics.

The amount of CO_2 emitted by an European refinery in 2007 ranged from about 3 kt to about 6 Mt per year (CITL, 2009b; Europia & CONCAWE, 2009d) depending on the type of refinery and energy integration. According to the reference document on best available technologies (BREF Refineries, 2003) the specific emissions of a refinery can range from 0.02 to 0.82 t CO_2/t of crude oil processed, although Europia & CONCAWE (2009d) are confident that the lower figure does not refer to a full refinery, but just a part of it.

In general, a refinery's emissions depend on the crude oil's weight (API) and the degree of cracking, determined by the product yield: a high share of light products (gasoline and diesel) requiring higher processing and more CO_2 emissions. Different fuels are burnt for various refining processes, resulting in different CO_2 emissions per unit of energy use (IEA, 2005).

There are numerous sources of CO_2 emissions in refineries. The main sources of CO_2 emissions in units of the mineral oil refineries can be summarised as follows (Öko Institut and Ecofys, 2008):

- Furnace units in the production of process heat, electricity and steam from fuels (fuel gas, heating oil and liquid gas)
- Coke combustion in the catalytic converters (catalytic crackers and reformers)
- Production of hydrogen and synthesis gas

- Calcination of petroleum coke
- Post-combustion furnaces for emissions (e.g. Claus gas, emissions from the manufacture or loading of bitumen)
- Gasifiers of heavy fractions
- Flares

Table 4 shows the average contribution of the various sources to refineries' emissions. The percentages given in the table represent worldwide averages from the year 2000 and as a consequence may not be fully representative for present operations in the EU. According the Europia and CONCAWE (2009d) this is particularly true for the maximum values for FCC catalysts and flare losses.

Table 4 Contribution of different sources to overall refinery GHG emissions, average and range on a CO_2-eq basis for worldwide operations in the year 2000 (Öko Institut and Ecofys, 2008)

	Contribution to overall GHG emissions (%, CO_2-eq basis)		
	Average	**Minimum**	**Maximum**
Direct combustion	85	56	100
- FCC Coke on Catalyst	19	0	61
- Other fuels	66	23	99
Indirect energy	8	0	35
Hydrogen generation	4	0	29
Flare loss	3	0	19
Methane	<1	0	1

A key source of energy CO_2 emissions in mineral oil refineries are combustion processes for the production of thermal energy. Furnace units are necessary in the processing operation of mineral oil when the temperature of input materials (e.g. for distillation) has to be increased (Öko Institut and Ecofys, 2008).

Process-related CO_2 emissions mainly occur due to the regeneration of catalytic converters such as the catalytic cracking unit and the reformers. Furthermore, process-related emissions also accrue during the gasification of heavy oil and hydrogen production as well as during the calcination of petroleum coke.

3 Benchmarking Methodology

3.1 Background

For a refinery with a given configuration, the emissions intensity is influenced by the following factors:

- Energy efficiency
- Fuel use (in general refinery fuel gas, natural gas, LPG, distillate fuel oil, residual fuel and coke). Emissions are relatively low when fuels such as refinery gas, low-sulphur fuels oil or natural gas are combusted. If heaters are fired with refinery fuel pitch or residuals, emissions can be significantly higher (Öko Institut and Ecofys, 2008).
- Feed composition
- Products (mix and grades)

Difficulties arise when comparing the emission intensity of different refineries: although all refineries process crude to make a broadly similar range of products (LPG, gasolines, and kerosene, gasoil/diesel and fuels oils), they are all different in terms of types of process units, relative and absolute size. This is illustrated by Entec (2006) which identified over hundred different plant configurations in 23 Member States (Öko Institut and Ecofys, 2008).

A single refinery will use different routes with different CO_2 footprints to make a certain product and production routes and products are interdependent, i.e. a refinery cannot produce only gasoline. Also, refineries with a relative simple configuration unable to process certain heavy fractions being part of their output, ship these substances to more complex refineries for further processing. As a result, energy consumption and CO_2 emissions do not readily correlate with simple indicators such as crude throughput, final product mix or the like and a benchmarking approach solely using these indicators would not reflect performance in terms of emissions. The difference in configurations due to different final product mixes and due to different treatment of intermediate fractions which either shipped or processed on-site should therefore be reflected in the benchmark approach for refineries.

Other challenges that exist when comparing refineries are differences in degree of incorporation of emissions from on-site production of electricity, the import and export of electricity and steam, and the integration and overlap with the petrochemical industry (steam cracking, hydrogen and synthesis gas production, propylene production and production of aromatics).

Based on a qualitative assessment, Öko Institut and Ecofys (2008) recommended to perform an in-depth analysis and to investigate specifications of two benchmarking methodologies that do take into account differences in refinery configurations: the Solomon's "complexity weighted barrel" (CWB) approach and a "hybrid" approach. The Solomon approach makes use of a scaling based on a breakdown of the refinery in its component parts and will be discussed in detail the next section. The hybrid is based on uniform benchmark (emissions per tonne of crude oil) with some corrections for specific units.

Of these two approaches, the Solomon approach accounts to a greater extent for differences in the configuration of refineries. In the 2008 study it was acknowledged that the development of a "hybrid" system would require additional efforts. Drawbacks of CWB approach were considered to be the lack of transparency and the fact that the methodology is property of Solomon.

Meanwhile however, the sector organizations CONCAWE and Europia have investigated and further developed the Solomon CWB approach, which resulted in the Solomon "CO_2 weighted tonne" (CWT) approach. This approach is owned by CONCAWE who is free to promote it and apply it within Europe. To use the methodology no further agreement or contract between either CONCAWE or individual refiners and Solomon is necessary. Also, all parameters needed to perform the calculations necessary to apply the methodology can become publicly available. In addition, the sector organizations have offered Ecofys and the Commission the opportunity to review with Solomon how these parameters were derived. Such a review would however be beyond the scope of the present project.

Considering the above, we regard the CWT approach to be sufficiently transparent and therefore propose to use it to benchmark refineries.

3.2 The CWT approach

When using the CWT approach, the single "product" of the refinery is the CWT. For the calculation of the "production" of a refinery in terms of CWTs Solomon defined a list of 51 generic process units from their comprehensive list of about 170 actual units (see Appendix B). In order to achieve this, process units were pooled together. It is estimated that refineries will be typically contain 10-15 defined process units. The maximum number of process units for EU refineries is 26 (Europia and CONCAWE, 2009d).

Each of the generic process unit was assigned an emission factor relative to crude distillation, which is denoted as the CWT factor (see Table 5). The CWT factor of the crude distillation unit is taken as 1, and factors of other units are representative of their CO_2 emission intensity at an average level of energy efficiency, for the same standard fuel type for each process units for combustion, and for average process emissions of the process unit. As refining is an integrated activity the standard factor used to define the CWT factor of each process unit refers to the net energy consumption i.e. deducing any steam or electricity production. Taking this standard approach for the CWT factor means that differences in actual emissions should be due to higher or lower energy efficiency and fuel emission factor. To develop the factors Solomon used an extensive database on some 200 worldwide refineries which have for many years, supplied energy consumption data, as well as consulted process licensors. The present set of values has been in use since 2006. It is important to note that the CWT factors are only used as weighing factors between individual units within the refinery. The actual benchmarking (i.e. measuring difference in performance) is done when comparing the actual emissions to total CWT of the refinery.

Since the CWT factors serve as weighting factors for different process units, changing a factor would only change the relative impact of that process unit. Lowering CWT factors as such would thus not automatically result in a steeper benchmark curve and/or a higher level of free allocation to refineries.

Table 5 Basis for throughput and CWT factors for CWT process units (Europia & CONCAWE, 2009b)

CWT process unit	Basis for throughput[1]	CWT factor[2]
Atmospheric Crude Distillation	F	1.00
Vacuum Distillation	F	0.85
Visbreaker	F	1.40
Delayed Coker	F	2.20
Fluid Coker	F	7.60
Flexicoker	F	16.60
Fluid Catalytic Cracking	F	5.50
Other Catalytic Cracking	F	4.10
Thermal Cracking	F	2.70
Distillate/Gas oil hydrocracker	F	2.85
Residual Hydrocracker	F	3.75
Naphtha Hydrotreater	F	1.10
Kerosene/Diesel Hydrotreater	F	0.90
Residual Hydrotreater	F	1.55
VGO Hydrotreater	F	0.90
Reformer (inc. AROMAX)	F	4.95
Solvent Deasphalter	F	2.45
Alky/Poly/Dimersol	P	7.25
C4 Isom	R	3.25
C5/C6 isom	R	2.85
Coke Calciner	P	12.75
Hydrogen production, gas feed	P	296.00
Hydrogen production, liquid feed	P	348.00
Special fractionation for purchased NGL	F	1.00
Propylene	F	3.45
Asphalt	P	2.10
Polymer Modified Asphalt	P	0.55
Sulphur	P	18.60
Oxygenates	P	5.60
Aromatics		
Aromatic Solvent Extraction	F	5.25
Hydrodealkylation	F	2.45
TDP/TDA	F	1.85
Cyclohexane	P	3.00
Xylene Isom	F	1.85
Paraxylene	P	6.40
Ethylbenzene	P	1.55
Cumene	P	5.00

Continuation Table 5

CWT process unit	Basis for throughput[1]	CWT factor[2]
Lubricants		
Solvent extraction	F	2.10
Solvent dewaxing	F	4.55
Wax isomerisation	F	1.60
Lube Hydrocracking	F	2.50
Wax Deoiling	P	12.00
Lub & Wax Hydrofining	F	1.15
Solvents		
Solvent Hydrotreating	F	1.25
Solvent Fractionation	F	0.90
Miscellaneous		
Treatment & Compression for P/L gas sales	kW	0.45
POX Syngas for Hyd and methanol	SG	44.00
POX Syngas for fuel	SG	8.20
Methanol	P	-36.20
Air Separation	P (kNm^3 O_2)	8.80
Desalination	P (km^3)	1.15

[1] Fresh feed (F), reactor feed (R, includes recycle), product feed (P), synthesis gas production for POX unit (P)
[2] Dimensionless factor representing the average CO_2 emission intensity (per tonne of throughput/product) relative to atmospheric distillation. Factors are common to all refineries.

Definition of the product

The 'production' of a refinery in terms of CWTs represents a combination of the throughputs (or production) of the different process units, and therefore the 'activity' of the refinery. For each refinery the 'production' can be calculated in the following way (for a more a detailed calculation the reader is referred to appendix C):

- The amount of CWTs of each process unit is determined by multiplying its CWT factor by its intake during a given period;
- The amounts of CWTs of all process units are subsequently summed up;
- An amount of CWTs is added to account for off-sites and for non-crude feedstock.
    - o The correction for off sites reflects the fact that energy is required to operate the non-process assets such as tank farms, blending facilities, terminal as well as ancillary facilities such as effluent treatment etc. It is strongly related to the volume of crude process as well as to the total amount of CWTs.
    - o The correction for non-crude feedstock accounts for non-crude feedstocks (e.g. atmospheric residues or vacuum distillates) which are directly fed cold (or relatively cold) to the units downstream of the crude distiller and which therefore need be brought to the temperature level required when transferring material from the crude distiller to downstream units.

  To determine the correction, Solomon has developed a simplified empirical correlation that captures both aspects and involves a number of extra input parameters.
- A correction is made to exclude electricity use and production in order to be consistent with Art. 10a (1) of the amended Directive ("…No free allocation shall be made in respect of any electricity production…"). This correction will be discussed in detail below.

- Corrections are made to account for cross-boundary heat flows in order to ensure that each refinery is considered in an equal manner regardless of the permitting structure of the heat producing and heat consuming installations. These corrections will be discussed in detail below.

Validation of the approach

In order to verify whether or not the CWT is a suitable measure to compare different refineries, Solomon investigated the correlation between the amount of CWTs 'produced' by refineries and the actual CO_2 emissions for the same time period. They found that the correlation was not perfect, which may be expected as CWT is representative of a standard rather than the actual performance. Solomon further investigated the correlation by changing for each refinery the actual performance (resulting in the actual emissions) with the standardized performance regarding energy efficiency and fuel mix that form the basis for the CWT factors. This exercise demonstrated that over 99% of the scatter was related to performance in terms of energy efficiency and fuel emission factor. It was concluded that CWT is representative of the emissions of the refinery at a standard level of performance (Europia and CONCAWE, 2009b).

In other words, at equal performance, all refineries have the same relation between actual emissions and amount of CWTs 'produced'. Therefore, deviations from the ratio between the average actual CO_2 emissions and CWT (t CO_2/CWT) indicate differences in performance. In that way, the CWT approach allows comparison of all refineries taking into account differences in size and configuration.

Correction for electricity use and production

As mentioned earlier a correction must be made to exclude electricity use and production in order to be consistent with Art. 10a (1) of the amended Directive ("…No free allocation shall be made in respect of any electricity production …"). In the CWT approach, this correction is made in the following way (note that specific emissions are obtained by dividing emissions by production and that consequently both nominator and denominator need to be considered):

- The verified actual emissions are corrected by subtracting the emissions due to on-site electricity production. These emissions are calculated from the direct fuel consumption and emissions for gas turbines, and the direct fuel consumption and emissions to produce the portion of the energy content of the steam used to produce electricity in let-down or condensing turbines.
- The 'production' of CWTs is corrected by multiplying it with the ratio between the direct emissions and the direct plus indirect emissions. The indirect emissions are estimated by multiplying the electricity consumption with the emission factor for electricity production. As explained in Section 6.3 of the report on the project approach and general issues, the emission factor applied in the carbon leakage analysis (0.465 t CO_2/MWh) is applied. The direct emissions are estimated by subtracting the emissions of electricity production from the installation's verified actual emissions and adding the emissions from imported steam. The emissions from steam import are calculated using the average emission factor for heat production of all EU refineries.

Correction for cross-boundary heat flows
As mentioned earlier corrections for cross-boundary heat flows are needed in order to ensure that each refinery is considered in an equal manner regardless of the permitting structure of the heat producing and heat consuming installations. This is done in the following way:

- Steam export is corrected for by subtracting the deemed emissions from the exported steam from the actual verified emissions. The emissions from steam export are calculated using the emission factor for heat production of the refinery.
- Steam import is corrected for by adding the deemed emissions from the imported steam to the actual verified emissions. The emissions from steam import are calculated using the average emission factor for heat production of all EU refineries.

By doing so, it is ensured that in the calculation of the benchmark, all direct (i.e. fuel and steam) refinery related emissions are taken into account in the calculation. In the final allocation, the total amount of allowances based on the benchmark should be distributed over the refinery and (if applicable) the installations that supply heat to the refinery depending on the final choice of allocation for situations with cross-boundary heat flows (see Section 6.1 of the report on the project approach and general issues). Similarly, the allocation for the steam that is exported from the refinery can be calculated based on the allocation rule for the consumer of this steam and the rules on cross-boundary heat flows.

Overlap with petrochemical sector
Since refineries may incorporate steam cracking, hydrogen and synthesis gas production, propylene production and production of aromatics, the sector overlaps with the petrochemical industry and the industrial gas industry. We propose to follow the CWT approach for all hydrogen production and all aromatic production units. In the CWT approach, several hydrogen production and synthesis gas production units (from residual fuels) are included. This is inherent to the CWT methodology where the "choice of process units" as such is not benchmarked (see also under drawbacks of the methodology). As a result, also hydrogen and synthesis gas units outside refineries would be treated with different benchmarks according to this proposal, which is not in line with the general one-product-one-benchmark as outlined in Section 4.4.2 of the report on the project approach and general issues. It is therefore recommended to further simplify the CWT approach with respect to the number of hydrogen and synthesis gas production units so that a less technology-specific approach results for hydrogen units also outside refineries. It is recommended to further study this option in close cooperation with Europia, CONCAWE, Cefic (Chemical industry association) and EIGA (Industrial gas association), also because some of the CWT factors for the units are currently under discussion between SOLOMON and CONCAWE and because the properties of synthesis gas (e.g. the CO / H_2 ratio) that formed the basis for the CWT factor is currently not well defined in the methodology (CONCAWE, 2009).

For propylene production, we propose to use the CWT approach if the production takes place in a refinery, and to use the SOLOMON approach for steam crackers (see sector report on chemical industry) if the propylene is produced in a steam cracker. Using two methods for the same product is not in line with our one-product-one-benchmark principle (see Section 4.4.2 of the report on the project approach and general issues). In this particular situation however, we feel that breaking this principle is justified since developing a single benchmark for propylene production would require adaptations of both the SOLOMON approach for steam crackers and /or the CWT approach for refineries. These adaptations would not be straightforward and may limit the effectiveness of the methodologies.

Our proposal was discussed with the European sector organizations of the refinery industry (Europia and CONCAWE), the petrochemical industry (Cefic) and the industrial gas industry (EIGA). Although the principle of treating similar units in an equal way, regardless whether the unit is part of the chemical or refinery industry was supported by these organizations, a full support can obviously only be given after more detailed information on the CWT benchmark value is known.

Drawbacks of the methodology

A drawback of the CWT methodology is that steam produced in-house is an integral part of the benchmarking methodology (more efficient steam production or a less emission intensive fuel mix results in a lower specific t CO_2 figure), whereas steam crossing the boundaries is taken into account using an average emission factor and a standardized efficiency of heat generation. This issue is difficult to resolve, because taking into account the actual specific emission for the imported steam would require data from entities independent from the refinery. Given the relatively small importance of cross-boundary heat flows over the system boundaries, we regard this as acceptable.

For the reasons described in Section 3.1 we support the opinion that a benchmark for refineries should be corrected for different configurations that are used to produce the various products. However, the result of the CWT approach is that none of the configuration choices is part of the benchmark. The method does not seek to judge whether certain technological choices are preferable over others. As a result, refineries using exactly the same type of crude and produce an identical range of products still could theoretically get a different allocation, because they apply different units in their production. One could argue that the current CWT model should be adjusted so that it becomes less technology-specific, e.g. by adjusting the CWT of units that could be replaced by the less CO_2 intensive ones. Doing so would imply that one should be able to determine which process units can be replaced by less CO_2 intensive ones (with everything else remaining equal). Given the interdependency of process units, this would be extremely difficult and to a certain extent arbitrary. We therefore do not regard this as a preferable route.

4 Benchmark values

For each refinery it is possible to determine the specific emissions (on the basis of tCO_2/CWT) by filling in a relatively simple template. CONCAWE has collected data[3] for the years 2006, 2007 and 2008 and has constructed a benchmark curve. From this curve it will be possible to determine the average performance of the 10% most efficient installations.

According to CONCAWE, initial indications confirm that the methodology represents the EU refining population well although the amongst the final list of operating refineries some will not fall easily into the population to be benchmarked, because they are atypical in terms of product slate e.g. producing mostly specialties such as asphalts, lubricants, solvents, etc. Preliminary results showed that the greatest factor causing differences in specific emissions is energy efficiency rather than fuel mix (Europia & CONCAWE, 2009a).

According to preliminary data, it is expected that the final benchmark value is slightly below the first decile break point of 30 kg CO_2 / CWT with the average across the refinery population being 35 kg CO_2 / CWT (Europia, 2009). It should be stressed, however, that it is currently unclear how the atypical refineries mentioned above are treated in deriving this estimate and how the average of the 10% most efficient is exactly calculated. The value should thus be seen as very preliminary and should be used with caution.

[3] This data has not been officially verified

5 Additional steps required

To finalize the CWT benchmarking methodology for refineries, the following additional steps need to be made:

- The approach and weighting factors should be reviewed by independent third parties, the Commission services and/or Member States

- A list of exact definitions should be compiled for the units listed in Appendix B and of variables and parameters used in the approach (see Appendix C)

- The Norwegian refineries should be included in the assessment

- Upon delivery of a benchmark curve by the sector organizations, it needs to be assessed whether it was obtained using the approved methodology (as described in this report),

- Upon delivery of a benchmark curve, it should be assessed how atypical refineries have been taken into account and if this can be accepted.

- It should be further discussed between Europia, CONCAWE, EIGA and Cefic how the various hydrogen and synthesis gas units could be simplified, what definitions should apply for these units and what the correct CWT factors for these process units are.

6 Stakeholder comments

Europia and CONCAWE have reacted to our consultation paper on project approach and to the first draft report for the refinery sector (Europia and CONCAWE, 2009d). Also, throughout various discussions and correspondence the sector organisations have given their views on certain aspects of our proposal. The text below summarizes their comments of the according to our interpretation of their position:

1. We believe that in general the two reports represent a fair, well balanced and pragmatic assessment of the approach to allocation by benchmarking in general, and in particular to the CONCAWE allocation methodology proposed for the Refining of Mineral Oil ('Refining') sector.

2. We believe that the proposals we have discussed for use of the CONCAWE benchmarking methodology do meet the five starting points outlined in section 3 "Design of Benchmark-based allocation rules" in the Project approach paper. (Ecofys: for these starting points, see section 4.4 of the report on the project approach and general issues)

3. We also concur with your statements in section 3.3 (Ecofys: see section 4.4.3 of the report on the project approach and general issues) reflecting a flexible application of the criteria for product definition or grouping of products, "to ensure that benchmarks are not discouraged for those sectors for which benchmarking would be appropriate, but which do not strictly meet all the criteria."

4. We strongly concur with your statement that "(refining) CO2 emissions do not readily correlate with simple indicators such as crude throughput, product make or the like". We support your conclusion in the Refining report that our proposed methodology is "suited to compare different refineries and is flexible enough to come to a benchmarking methodology that is in line with the Directive"

5. Some installations that produce some oil products are not representative of the vast majority of the refineries and may not easily fit in the distribution; examples might be small speciality units for lubricant, solvents and bitumen production. We will propose an approach to identify these objectively and treat them fairly, whilst not distorting the benchmark applicable to the "mainstream" refineries.

6. Whilst we are aiming to include the largest possible proportion of the EU Refinery population within a single distribution curve, we cannot yet exclude that there may be "outliers". Two approaches to identify them could be:

- Either, plants that do not look like the majority of the population because they have specific production e.g. speciality asphalt refineries. These may not fit the curve at all.
- Or, plants that have specific characteristics that make them more efficient, but which cannot be replicated at other sites e.g. opportunities for district heating.

These should be recognised when setting the benchmark. The regression you propose (Ecofys: see section 4.4.1 of the report on the project approach and general issues) is one potentially attractive option; other options could be to identify these plants with clear and objective rules for excluding such plants; for example, based upon a product output range representative of the large majority of refineries.

7. We strongly agree with the principle of equal treatment irrespective of ownership (Ecofys: see section 6.1.1 of the report on the project approach and general issues).

8. We support the use of actual historical production figures to allocate allowances. However, careful selection of the reference period is essential for two reasons:
   - Refineries undertake large maintenance and projects shutdowns or “turnarounds” typically on a five year cycle; we prefer your proposal to use the highest year in a range of years. If an average period must be used, it should be a five-year average.
   - The New Entrants allowance applies for extensions after mid-2011; capacity expansion projects between the start of the reference period and mid-2011, if qualifying under the “to be defined” NE guidelines, should be included in the reference capacity. As you suggest, this could be done by taking the nameplate capacity with a typical industry utilisation rate.

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Appendix A: List of refineries

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
Austria	Raffinerie Schwechat	Schwechat	Refinery	2
Belgium	Antwerp (BRC)	Antwerp (BRC)	Refinery	2
	Total Raffinaderij Antwerpen	Antwerp	Refinery	2
	Exxonmobil Petroleum & Chemical Antwerp	Antwerp	Combined Refinery/Chemical	2
	Petroplus Refining Antwerp	Petroplus Refining Antwerp Bitumen	Specialized refinery: Bitumen plant	2
		Petroplus Refining Antwerp	Desulferisation unit	2
Bulgaria	LUKOIL Neftochim Bourgas AD	Bourgas	Combined Refinery/Chemical	99
	Balgarska Petrolna Rafineri[1 2]	Balgarska Petrolna Rafineria		2
	Insa Oil LLC [1 2]	Insa Oil LLC		2
Czech Republic	PARAMO-HS Pardubice	Pardubice	Refinery	2
	PARAMO-HS Kolín[1]	Kolin	Specialized refinery: Solvent production facility	2
	Česká rafinérská, Rafinérie Litvínov	Litvinov	Refinery	2
	Česká rafinérská, a.s. - rafinérie ropy Kralupy na	Kralupy	Refinery	2
Denmark	Shell Raffinaderiet Fredericia	Fredericia	Refinery	2
	Statoil Raffinaderiet	Kalundborg	Refinery	1
Finland	Porvoon jalostamo	Porvoo	Refinery	2
	Naantalin erikoistuotejalostamo	Naantali	Refinery	2
France	Raffinerie de Berre	Berre	Combined Refinery/Chemical	2
	SARA	SARA	Refinery	2
	PETROPLUS RAFFINAGE PETIT COURONNE SAS	Petit Couronne	Refinery	2
	ESSO RAFFINAGE SAF	Fos	Refinery	2
	ESSO RAFFINAGE SAF	Port-Jerome	Refinery	2
	Raffinerie de Lavera	Lavera	Refinery	2

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
	TOTAL FRANCE Raffinerie de Provence	La Mede	Refinery	2
	TOTAL FRANCE Raffinerie de Grandpuits	Grandpuits	Refinery	2
	RAFFINERIE DE REICHSTETT	CRR (Reichstett)	Refinery	2
	SRD - Société de la Raffinerie de Dunkerque	Dunkerque	Specialized refinery: lubricants	2
	TOTAL FRANCE Raffinerie des Flandres	Dunkerque	Refinery	2
	TOTAL FRANCE Raffinerie de Feyzin	Feyzin	Combined Refinery/Chemical	2
	TOTAL FRANCE Raffinerie de Donges	Donges	Refinery	2
	TOTAL FRANCE Raffinerie de Normandie	Gonfreville	Refinery	2
Germany	Petroplus Raffinerie Ingolstadt GmbH	Ingolstadt	Refinery	2
	BP Gelsenkirchen	BP Gelsenkirchen Horst site	Refinery	2
		BP Gelsenkirchen Scholven site	Combined Refinery/Chemical, includes steam cracker and POX	2
	OMV Deutschland GmbH	Burghausen	Combined Refinery/Chemical	2
	TOTAL Bitumen Deutschland GmbH	Brunsbuttel	Specialized refinery: Bitumen plant	2
	BAYERNOIL Raffineriegesellschaft mbH	Neustadt site	Refinery	2
		Ingolstadt site	Refinery	2
		Vohburg site	Refinery	2
	MineralOlraffinerie Oberrhein GmbH & Co. KG	MIRO (Karlsruhe)	Refinery	2
		MIRO (Karlsruhe)	Refinery	2
	H & R Chemisch-Pharmazeut	Hamburg/ Neuhof	Specialized refinery: lubricants/ bitumen	2
	Shell Deutschland Oil GmbH Harburg	Harburg	Refinery, process	2
		Harburg	Specialized refinery: lubricants	2

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
	Deutsche BP AG ErdOl	Lingen	Refinery, process	2
	PCK Raffinerie GmbH	Schwedt	Refinery Hydrogen	2
		Schwedt	Refinery Process	2
		Schwedt	Refinery Power plant	2
	TOTAL Raffinerie Mitteldeutschland GmbH	Leuna	Refinery	2
		RKB Raffinerie-Kraftwerks-Betriebs GmbH	Power plant	2
	Shell Deutschland Oil GmbH Rheinland	Rheinland Wesseling site	Refinery	2
		Rheinland Godorf site	Combined Refinery/Chemical	2
		Raffineriekraftwerk Wesseling	Power plant	1
		Kraftwerk Godorf	Power plant	1
	H & R Oelwerke	Salzbergen	Specialized refinery: lubricants/ bitumen	2
	Wilhelmshavener Raffineriegesellschaft mbH	Wilhelmshaven	Refinery	2
	Shell Deutschland Oil GmbH	Heide refinery	Refinery	2
			Power plant	1
	Holborn Europa Raffinerie GmbH[3]	Harburg (Holborn)	Refinery	2
Greece	HELLENIC PETROLEUM S.A. (THESSALONIKI REFINERY)	Thessaloniki	Combined Refinery/Chemical	2
	HELLENIC PETROLEUM S.A. (ELEFSIS REFINERY)	Elefsis	Refinery	2
	HELLENIC PETROLEUM S.A. (ASPROPYRGOS REFINERY)	Aspropyrgos	Refinery	2
	MOTOR OIL HELLAS - CORINTH REFINERIES S.A.	Agii Theodori	Refinery	2
Hungary	MOL Rt. Dunai Finomító	Szazhalombata	Refinery	2
	MOL Rt. Tiszai Finomító[1]	Tiszai	HDS unit	1

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
	MOL Rt. Zalai Finomító[1]	Zalai	Specialized refinery: Bitumen plant	1
Ireland	ConocoPhillips Whitegate Refinery	Whitegate	Refinery	2
Italy	RAFFINERIA DI AUGUSTA	Augusta	Refinery	2
	S.A.R.P.O.M S.p.A.	Trecate	Refinery	2
	Raffineria di greggi e oli pesanti	Ravenna	Refinery	2
	IPLOM S.p.A. – Raffineria di Busalla	Busalla	Refinery	2
	RAFFINERIA DI SANNAZZARO	Sannazzaro	Refinery	2
	RAFFINERIA DI CREMONA	Cremona	Refinery	2
	Raffineria di Petrolio	Mantova	Refinery	2
	Raffineria di Venezia	Porto Marghera	Refinery	2
	Raffineria api di Falconara Marittima	Falconara	Refinery	2
	Raffineria di Livorno	Livorno	Refinery	2
	Raffineria di Roma	Roma	Refinery	2
	Raffineria di Taranto	Taranto	Refinery	2
	Raffineria di Milazzo	RAM (Milazzo)	Refinery	2
	Raffineria di Gela S.P.A.	Gela	Refinery	2
	RAFFINERIA ISAB IMPIANTI	Priolo Nord	Refinery	2
		ERG NUOVE CENTRALI - IMPIANTI NORD	Cogen	2
		Priolo Sud (Melilli)	Refinery	2
		ERG NUOVE CENTRALI - IMPIANTI SUD	Cogen	2
	Saras SpA	Sarroch	Refinery	2
Lithuania	Mažeikių nafta, AB	Mazeikiu	Refinery	2
Netherlands	ESSO Raffinaderij Rotterdam	Rotterdam	Refinery	2
	Kuwait Petroleum Europoort B.V.	Rotterdam	Refinery	2
	BP Raffinaderij Rotterdam B.V.	NRC (Rotterdam)	Refinery	2
	Shell Nederland Raffinaderij BV	Pernis	Combined Refinery/Chemical	2
	Total Raffinaderij Nederland NV	Vlissingen	Refinery	2
	Koch HC Partnership B.V.	Rotterdam	Refinery	2

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
Poland	Rafineria Lotos Gdansk	INSTALACJA RAFINERYJNA GRUPA LOTOS	Refinery	2
		INSTALACJA RAFINERYJNA LOTOS ASFALT GDANSK	Refinery	2
		ELEKTROCIEPlOWNIA LOTOS - GDANSK	Power plant	1
	Rafineria Lotos Jaslo[(1)]	INSTALACJA RAFINERYJNA LOTOS JASLO	Refinery	2
		INSTALACJA RAFINERYJNA LOTOS ASFALT JASLO	Refinery	2
	Rafineria Nafty Jedlicze S.A.	INSTALACJA RAFINERYJNA RAFINERIA JEDLICZE	Refinery	2
	Rafineria Plock – Orlen	INSTALACJA RAFINERYJNA PKN ORLEN PLOCK	Refinery	2
		INSTALACJA RAFINERYJNA ORLEN ASFALT PLOCK	Refinery	2
		ELEKTROCIEPLOWNIA ORLEN - PLOCK	Power plant	1
		INSTALACJA OKSYDACJI ASFALTOW ORLEN ASFALT	Refinery	2
	RAFINERIA TRZEBINIA SA[1]	INSTALACJA RAFINERYJNA RAFINERIA TRZEBINA	Refinery	2
Portugal	Petrýleos de Portugal – Petrogal S.A	Sines	Refinery	2
	Petrýleos de Portugal - Petrogal S.A	Leca	Refinery	2
Romania	Combinatul Petrochimic ARPECHIM Pitesti	Arpechim	Combined Refinery/Chemical	2
	PETROBRAZI	Petrobrazi	Refinery	2
	SC PETROTEL - LUKOIL SA	Petrotel	Refinery	2
	SC RAFO SA	Onesti	Combined Refinery/Chemical	2
	SC Rompetrol Rafinare SA	Petromidia	Combined Refinery/Chemical	2
	SC PETROCHEMICAL TRADING SRL[1 4]	Damanesti		2
	SC Rafinaria Astra Romana SA[1 4]	Astra Ploiesti		2

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
	SC RAFINARIA STEAUA ROMANA SA CAMPINA [1 4]	STEAUA Campina		2
	SC Romp.Rafin.SA Pdl Rafin.Vega Ploiesti [1]	Vega	Solvent production facility	2
Slovakia	Slovnaft, a.s.	Slovnaft (Bratislava)	Combined Refinery/Chemical	2
Spain	Huelva (La Rabida)	Compania Espanola de Petroleos, S.A.	Refinery	2
		GENERACION ELECTRICA PENINSULAR, S.A.	Cogen	2
	San Roque	Compania Espanola de Petroleos, S.A.	Refinery	2
		GENERACION ELECTRICA PENINSULAR, S.A.	Cogen	2
	Teneriffe	Compania Espanola de Petroleos, S.A.	Refinery	2
	Repsol Petroleo, s.a.	Puertollano	Combined Refinery/Chemical	2
	Asfaltos Espanoles S.A.	Tarragona	Specialized refinery: Bitumen plant	2
	Repsol Petroleo, s.a.	Tarragona	Combined Refinery/Chemical	2
	BP Oil Refineria de Castellon S.A	Castellon	Refinery	2
	Repsol Petroleo, s.a.	La Coruna	Refinery	2
	Repsol Petroleo, s.a.	Cartagena	Refinery	2
	Lubricantes del Sur, S.A. - LUBRISUR		Specialized refinery: Luboil plant	1
	Petroeos del Norte, SA	Petronor (Somorrostro)	Refinery	2
Sweden	Göteborgs Raffinaderiet	Gothenburg	Specialized refinery: Bitumen plant	2
	Nynäshamns Raffinaderiet	Nynasham	Specialized refinery: Bitumen plant	2
	Preem Raffinaderi AB, raffinaderiet	Gothenburg	Refinery	2
	Scanraff	Lysekil	Refinery	2
	Shell Raffinaderi AB	Gothenburg	Refinery	2
United Kingdom	Eastham Refinery Ltd	Eastham	Refinery	2
	Esso Petroleum Company Ltd	FAWLEY COGEN	Cogen for Fawley	2

Country	Refinery name	Installation name / location	Type of location	Main activity (CITL)
		Esso Petroleum Company Ltd	Combined Refinery/Chemical	2
		Fawley		2
	Grangemouth Refining	Grangemouth	Refinery	2
	Humber Refinery	Killingholme	Refinery	2
	Murco Petroleum Milford Haven Refinery	Milford Haven	Refinery	2
	Nynas UK AB Dundee	Dundee	Specialized refinery: Bitumen plant	2
	Petroleum Processes	Stanlow	Combined Refinery/Chemical	2
	Petroplus Refining Teesside Limited	Teeside	Combined Refinery/Chemical	2
	Petroplus Refining and Marketing Ltd	Coryton	Refinery	2
	Texaco Limited, Pembroke	Pembroke	Refinery	2
	Total Lindsey Oil Refinery	Humberside	Refinery	2

Source: Europia and CONCAWE, 2009e
[1] Status needs to be checked
[2] NACE 23.20 but not included in benchmarking exercise
[3] For local reasons the refinery has been issued separate permits for each main process unit
[4] Shutdown

Appendix B: CWT process units

CWT process unit	Actual process units used by original Solomon approach for benchmarking refinery energy efficiency
Atmospheric Crude Distillation	Mild Crude Unit
	Standard Crude Unit
Vacuum Distillation	Mild Vacuum Fractionation
	Standard Vacuum Column
	Vacuum Fractionating Column
	Vacuum distillation factor also includes average energy and emissions for Heavy Feed Vacuum (HFV) unit. Since this is always in series with the MVU, HFV capacity is not counted separately.
Visbreaking	Atmospheric Residuum (w/o a Soaker Drum)
	Atmospheric Residuum (with a Soaker Drum)
	Vacuum Bottoms Feed (w/o a Soaker Drum)
	Vacuum Bottoms Feed (with a Soaker Drum)
	Visbreaking factor also includes average energy and emissions for Vacuum Flasher Column (VAC VFL) but capacity is not counted separately.
Fluid Coking	Fluid Coking
Flexicoking	Flexicoking
Delayed Coking	Delayed Coking
Thermal Cracking	Thermal cracking factor also includes average energy and emissions for Vacuum FlasherColumn (VAC VFL) but capacity is not counted separately.
Fluid Catalytic Cracking All FCC categories are merged together. The simplification case factor also includes energy and emissions related to average EU27 special fractionation correlated with FCC.	Fluid Catalytic Cracking Mild Residuum Catalytic Cracking Residual Catalytic Cracking
Other Catalytic Cracking	Houdry Catalytic Cracking
	Thermofor Catalytic Cracking
Distillate / Gasoil Hydrocracking	Mild Hydrocracking
	Severe Hydrocracking
	Naphtha Hydrocracking
Residual Hydrocracking	H-Oil LC-Fining™ and Hycon
Naphtha/Gasoline Hydrotreating	Benzene Saturation
	Desulfurization of C4–C6 Feeds
	Conventional Naphtha H/T
	Diolefin to Olefin Saturation
	FCC Gasoline H/T
	Olefinic Alkylation of Thio S
	Selective H/T of Pygas/Naphtha
	Pygas/Naphtha Desulfurization
	Selective H/T of Pygas/Naphtha

CWT process unit	Actual process units used by original Solomon approach for benchmarking refinery energy efficiency
	Naphtha hydrotreating factor includes energy and emissions for Reactor for Selective H/T (NHYT/RXST) but capacity is not counted separately.
Kerosene Hydrotreating	Aromatic Saturation
	Conventional H/T
Diesel Hydrotreating	Aromatic Saturation
	Conventional Distillate H/T
	High Severity DistillateH/T
	Ultra-High Severity H/T
	Middle Distillate Dewaxing
	S-Zorb™ Process
Residual Hydrotreating	Desulfurization of Atmospheric Residuum Desulfurization of Vacuum Residuum
Heavy Gas Oil Hydrotreating	HDS and Hydrodenitrification Hydrodesulfurization (HDS)
Catalytic Reforming Factor includes energy and emissions related to average EU27 special fractionation (DIP, NAPS, and REFS) correlated with Reforming.	Continuous Regeneration Cyclic Semi-Regenerative AROMAX
Solvent Deasphalting	Conventional Solvent
	Supercritical Solvent
Alkylation / Polymerization Factor includes energy and emissions related to average EU27 special fractionation (DIB and ALKYS) correlated with alkylation and polymerization.	Polymerization C3 Olefin Feed Polymerization C3/C4 Feed Dimersol Alkylation with HF Acid Alkylation with Sulfuric Acid Factor for alkylation/polymerization includes energy and emissions for acid regeneration (ACID), but capacity is not counted separately.
C4 Isomerization Factor also includes energy and emissions related to average EU27 special fractionation (DIB) correlated with C4 isomerization.	C4 Isomerization
C5/C6 Isomerization Factor also includes energy and emissions related to average EU27 special fractionation (DIH) correlated with C5/C6 isomerization.	Factor for C5/C6 isomerization includes energyand emissions for ISOSIV (U18), but capacity is not counted separately.
Coke Calcining	Vertical-Axis Hearth
	Horizontal-Axis Rotary Kiln
Hydrogen Production	Steam Methane Reforming
	Steam Naphtha Reforming
	Partial Oxidation Units of Light Feeds
	Factor for hydrogen production includes energyand emissions for purification (H2PURE), but capacity is not counted separately.

CWT process unit	**Actual process units used by original Solomon approach for benchmarking refinery energy efficiency**
Special Fractionation	Except for Fractionation of Purchased NGL, Solvent Products and Propane/Propene Splitting, which have separate entries, Special Fractionation is excluded. Factors for related refining and aromatic functions include appropriate allowances for these fractionators
Propylene Production	Chemical Grade Polymer grade
Asphalt and Road Oil	Asphalt & Bitumen Manufacture
Sulfur Recovery	Sulfur Recovery Unit Factor for sulfur recovery includes energy and emissions for tail gas recovery (TRU) and H2S Springer Unit (U32), but capacity is not counted separately.
Oxygenate Production	MBTE Distillation Units MTBE Extractive Units ETBE TAME
Aromatics	
Aromatic Solvent Extraction and Separation	ASE: Extraction Distillation ASE: Liquid/Liquid Extraction ASE: Liq/Liq w/ Extr. Distillation ASE factor includes typical energy and emissions for the following columns: Benzene Column (BZC) Toluene Column (TOLC) Xylene Rerun Column (XYLC) Heavy Aromatics Column (HVYARO)
Hydrodealkylation	Hydrodealkylation
TDP/TDA	Toluene Disproportionation / Dealkylation
Cyclohexane Production	Cyclohexane
Xylene Isomerization	Xylene Isomerization
Paraxylene Production	PX: Adsorption PX: Crystallization PX factor includes typical energy and emissions for the following columns: Xylene Splitter (XYLS) Orthoxylene Rerun Column (OXYLRC)
Ethylbenzene	Ethylbenzene EB factor includes typical energy and emissions for Ethylbenzene Distillation (EBZD).
Cumene	Cumene
Lubes	
Solvent Extraction	Solvent is Furfural Solvent is NMP Solvent is Phenol Solvent is SO2
Solvent Dewaxing	Solvent is Chlorocarbon Solvent is MEK/Toluene Solvent is MEK/MIBK Solvent is propane

CWT process unit	Actual process units used by original Solomon approach for benchmarking refinery energy efficiency
Catalytic Wax Isomerization	Catalytic Wax Isomerization and Dewaxing
	Selective Wax Cracking
Lube Hydrocracker	Lube Hydrocracker w/ Multi-Fraction Distillation
	Lube Hydrocracker w/ Vacuum Stripper
	Lube H/F w/ Vacuum Stripper
	Lube H/T w/ Multi-Fraction Distillation
	Lube H/T w/ Vacuum Stripper
Wax Deoiling	Deoiling: Solvent is Chlorocarbon
	Deoiling: Solvent is MEK/Toluene
	Deoiling: Solvent is MEK/MIBK
	Deoiling: Solvent is Propane
Lube/Wax Hydrotreating	Lube H/F w/ Vacuum Stripper
	Lube H/T w/ Multi-Fraction Distillation
	Lube H/T w/ Vacuum Stripper
	Wax H/F w/ Vacuum Stripper
	Wax H/T w/ Multi-Fraction Distillation
	Wax H/T w/ Vacuum Stripper
Solvents	
Solvent Hydrotreating	U1 – Solvent Hydrotreating
Solvent Fractionation	Solvent Fractionation
Miscellaneous	
Treatment and Compression of Fuel Gas for Product Sales	U31 – Treatment and Compression of Fuel Gas for Sales
Syngas Production for H2 and Methanol Feedstock	Factor includes energy and emissions for CO Shift and H2 Purification (U71) but capacity is not counted separately.
Partial Oxidation of Residuum for Fuel	U73 – POX Syngas for Fuel
Methanol	Methanol
Air Separation	U79 – Air Separation Unit
Fractionation of purchased NGL	De-ethaniser
	De-propaniser
	De-butaniser
Polymer-Modified Asphalt	Polymer-Modified Asphalt Blending
Desalination	Desalination

Source: Europia & CONCAWE, 2009b

Appendix C: Calculations to determine specific emissions (t CO_2/CWT)

Below follows a calculation of the specific emissions (t CO_2/CWT) should be done for each refinery. Although the calculation may appear somewhat complex, the approach is actually straightforward. Europia & CONCAWE have prepared a simplified example of the approach in a spreadsheet which better than the calculation below explains the methodology.

CWT

For each process unit the CWT factor is multiplied by its intake during a given period and all such products are summed up:

$$CWTprocess = \sum_{i=1}^{N} CWTfactor_i \times Throughput_i \qquad (1)$$

where $CWTprocess$ is the resulting amount of CWTs, $CWTfactor_i$ denotes the CWT factor that corresponds to process unit i. $Throughput_i$ denotes the throughput of process unit i, and N signifies the number of distinguished process units.

The final number of CWTs of a refinery ($TotalCWT$) is calculated as follows:

$$TotalCWT = (CWTprocess + Corr_{OffSite/NonCrudeFeedstock}) \times CorrFac_{Elec.} \qquad (2)$$

where:

$Corr_{OffSite/NonCrudeFeedstoc}$ denotes the amount of CWTs added to correct for off sites and for non-crude feedstock, and $CorrFac_{Elec.}$ denotes the factor to correct for electricity use.

Correction for off sites and non-crude feedstock

In determining $Corr_{Offsite/NonCrudeFeedstock}$ use is made of a simplified empirical correlation that is linked to total CWT and crude intake.

Correction for electricity

The factor to correct for electricity use ($CorrFac_{Elec.}$) is determined with:

$$CorrFac_{Elec.} = \frac{Em_{direct}}{Em_{direct} + Em_{Elec.Consumed,deemed}} = \ldots$$
$$\ldots = (Em_{Total,actual} - Em_{Elec.Generated,actual} + Em_{Steamimport,deemed}) / \ldots$$
$$\ldots / (Em_{Total,actual} - Em_{Elec.Generated,actual} + Em_{Steamimport,deemed} + Em_{Elec.GeneratedandConsumed,deemed} \cdots$$
$$\ldots + Em_{Elec.import,deemed})$$

(3)

where
Em_{direct} denotes direct emissions at the refinery net of emissions due to on-site electricity generation and due to imported steam,
$Em_{Elec.Consumed,deemed}$ denotes the deemed emissions from consumed electricity (both from imported electricity ($Em_{Elec.import,deemed}$) and from electricity generated onsite ($Em_{Elec.GeneratedAndConsumed,deemed}$).
$Em_{Total,actual} - Em_{Elec.Generated,actual}$ denotes the verified emissions of the refinery net of emissions due to electricity generation at the refinery
$Em_{Steamimport,deemed}$ denotes the deemed emissions from the production of imported steam

Emissions

Total verified emissions
The verified emissions of a refinery ($Em_{Total,actual}$) are determined by multiplying the amount of each fuel burned ($FuelBurned_j$) by the emission factor of that fuel ($EmFactor_{FuelBurned,j}$) and adding all terms. To this resulting amount the sum of process emissions $Em_{process,k}$ are added:

$$Em_{Total,actual} = (\sum_{j}^{M} FuelBurned_j \times EmFactor_{FuelBurned,j}) + (\sum_{k}^{O} Em_{process,k}) \quad (4)$$

where M signifies the number of distinguished fuels and O the number of distinguished processes with process emissions.

Emissions from generated electricity
The actual emissions from electricity generated ($Em_{Elec.Generated,actual}$) are determined as follows:

$$\begin{aligned} Em_{Elec.Generated,actual} &= Em_{ElecGen,CHP} + Em_{Elec,Gen,Turbine} = \ldots \\ \ldots &= ElecGen_{CHP} \times EmFactor_{CHP} + ElecGen_{Turbine} \times EmFactor_{Turbine} \end{aligned} \quad (5)$$

Where $Em_{ElecGen,CHP}$ denotes the emissions due to electricity generation by CHP units, and $Em_{Elec,Gen,Turbine}$ the emissions due to electricity by extraction/condensation steam turbines. $ElecGen_{CHP}$ and $ElecGen_{turbine}$ denote the amount of electricity generated by CHP units and extraction/condensation steam turbines, respectively. $EmFactor_{CHP}$ and $EmFactor_{Turbine}$ denote the corresponding emission factors and are determined as follows:

$$EmFactor_{CHP} = \left(\frac{Em_{NetElecproduced}}{NetElecproduced} \right)_{CHP} = ...$$

$$... = \left(\frac{(Energy_{FuelIn} - Energy_{SteamOut}) \times EmFactor_{Fuel}}{NetElecproduced} \right)_{CHP} \quad (6)$$

$$EmFactor_{Turbine} = \left(\frac{Em_{NetElecproduced}}{NetElecproduced} \right)_{Turbine} = ...$$

$$.... = \left(\frac{(EnergyToElectricty_{Steam} / GeneratorEff) \times EmFactor_{Fuel}}{EnergyToElectricty_{Steam} \times GeneratorEff \times TurbineEff} \right)_{Turbine} \quad (7)$$

where $NetElecproduced$ denoted the net electricity produced and $Em_{NetElecproduced}$ the emissions corresponding to that electricity. In case of CHP, these emissions are calculated by taking the difference of energy content of the fuel used ($Energy_{FuelIn}$) and the part of that energy used for heat (steam) generation ($Energy_{SteamOut}$) in line with a reference boiler efficiency as proposed in Section 3.2 of the report on the project approach and general issues and multiplying that amount by the emission factor of the fuel used ($EmFactor_{Fuel}$). In case of extraction/condensation steam turbines, the emissions are calculated by first dividing the energy (in the form of steam) used to produce electricity ($EnergyToElectricty_{Steam}$) by the generator efficiency ($GeneratorEff$). The result is subsequently multiplied by the emission factor of the used fuel ($EmFactor_{Fuel}$). The net produced electricity ($NetElecproduced$) is determined by multiplying the energy (in the form of steam) used to produce electricity ($EnergyToElectricty_{Steam}$) by the generator efficiency ($GeneratorEff$) and the turbine efficiency ($TurbineEff$).

Emissions from consumed electricity

Deemed emissions related to electricity consumption $Em_{Elec.Consumed,deemed}$ are calculated using:

$$Em_{Elec.Consumed,deemed} = Em_{Elec.import,deemed} + Em_{Elec.GeneratedAndConsumed,deemed} \quad (8)$$

$$Em_{Elec.import,deemed} = Elec_{import} \times EmFactor_{Elec,EU} \quad (9)$$

$$Em_{Elec.GeneratedAndConsumed,deemed} = (Elec_{Generated} - Elec_{export}) \times EmFactor_{Elec,EU} \quad (10)$$

where $Elec_{import}$ denotes the imported electricity and $EmFactor_{Elec,EU}$ the EU averaged emission factor for electricity, $Elec_{Generated}$ denotes the electricity generated onsite, and $Elec_{export}$ the exported electricity.

Emissions from imported steam

$Em_{Steam.import,deemed}$ denotes the deemed emissions from outsourced steam production, which is calculated as follows:

$$Em_{Steam.import,deemed} = SteamIn \times \frac{EmFactor_{EUfuel}}{HeatprodEff_{deemed}} \tag{11}$$

where $SteamIn$ denotes the imported steam and $EmFactor_{EUfuel}$ denotes the fuel averaged emission factor of all refineries in Europe, and $HeatprodEff_{deemed}$ a assumed heat production efficiency.

Emissions from exported steam
$Em_{Steam.export,deemed}$ denotes the deemed emissions from the production of steam, which is calculated with as follows:

$$Em_{Steam.export,deemed} = SteamOut \times \frac{EmFactor_{energy,refinery}}{HeatprodEff_{deemed}} \tag{12}$$

where $SteamOut$ denotes the exported steam, $EmFactor_{energy,refinery}$ the average emission factor of all energy used in refineries, and $HeatprodEff_{deemed}$ a assumed heat production efficiency.

Specific emissions (t CO_2/CWT)
The specific emissions ($Spec.Em$) can now be calculated as follows:

$$Spec.Em = (Em_{Total,actual} - Em_{Elec.Generated,actual} + Em_{Steam.import,deemed} - \ldots \\ \ldots Em_{Steam.export,deemed}) / TotalCWT \tag{13}$$